Ministry of Road Transport & Highways

GUIDELINES FOR MAINTENANCE MANAGEMENT OF PRIMARY, SECONDARY AND URBAN ROADS

Published by
Indian Roads Congress
on behalf of the Govt. of India,
Ministry of Road Transport & Highways

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FOREWORD

It is with pleasure that I present to you this excellent document containing the "Guidelines for Maintenance Management of Primary, Secondary and Urban Roads" of our country. A well developed and properly maintained highways network is essential for the overall socio-economic development of any country. Lately, the Government have been laying great emphasis on the development of roads. On account of the poor condition of our roads alone the country bears a heavy economic cost. Rough estimates suggest that more than 50 per cent of the length of primary road network in this country needs immediate attention. Our maintenance and rehabilitation measures need to be on scientific evaluation of the condition of the pavements. We have to utilize our scarce resources in an optimal way.

Pavement Maintenance Management System (PMMS), involves matching of resources, time, materials, labour, equipments, funds, etc. in a scientific manner. PMMS, when developed and adopted to the requirements of our roads of different categories, will certainly yield fruitful results.

The guidelines given in the publication provide details of the data items, systematic methodology, intervention level for decision makings, caliberation needs, manpower requirement, for data collection, updation of database, training requirements, etc. and details of the State-of-the-Art equipment needed for development of PMMS.

These guidelines are the result of untiring efforts made by the officers and the staff of the Ministry of Road Transport & Highways, Indian Roads Congress, Central Road Research Institute, IIT, Roorkee and Bangalore University. I would like to express my appreciation of the commendable efforts put in by S/Shri A.P.S. Sethi, Chief Engineer and S.S. Nahar, Superintending Engineer of the Ministry of Road Transport & Highways, Shri G. Sharan, Secretary, IRC, Shri V.K. Sood, Project Co-ordinator, CRRI, Dr. S.S. Jain, IIT, Roorkee and Dr. A. Veeraragavan, Bangalore University. I would also like to acknowledge the services of S/Shri U.C. Katara, J.H. Eligar, Executive Engineers and Mrs. Sumita Banerjee, Stenographer of the Ministry of Road Transport & Highways and Shri S.C. Kakkar, Under Secretary, IRC, whose dedicated assistance helped in expediting this important work.

I hope, this publication will prove to be useful for all highway engineers. This is a live document. This Ministry would welcome your feedback on the document. This will enable us to improve it further.

(Ashoke Joshi)
Secretary to Govt. of India
Ministry of Road Transport & Highways

Place : New Delhi
Date : June, 2003

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ABBREVIATIONS

Sl. No	Item	Description
1.	NH	National Highway
2.	SH	State Highway
3.	MDR	Major District Road
4.	ODR	Other District Road
5.	VR	Village Road
6.	M&R	Maintenance and Repairs
7.	OR	Ordinary Renewals
8.	PR	Periodical Renewals
9.	SR	Special Repairs
10.	FDR	Flood Damage Repairs
11.	BT Surface	Black Topped Surface
12.	WBM	Water Bound Macadam Surface
13.	MR-I	Metal Renewal – 75 mm
14.	MR-II	Metal Renewal – 60 mm
15.	SD-I	One Coat of Surface Dressing
16.	SD-II	Two Coat of Surface Dressing
17.	PC+SC	20 mm Pre-Mix Carpet with Seal Coat
18.	MSS	20 mm Mix Seal Surfacing
19.	SDBC	25 mm Semi-dense Bituminous Carpet
20.	BC-I	25 mm Bituminous Concrete
21.	BC-II	40 mm Bituminous Concrete
22.	AC	Asphalt Concrete
23.	LC	Levelling Course
24.	SPT	Semi-Permanent Timber
25.	CVD	Commercial Vehicles/day
26.	VOC	Vehicle Operation Cost
27.	R&B	Road and Building
28.	DEE	Deputy Executive Engineer
29.	SO	Section Officer
30.	MoRT&H	Ministry of Road Transport & Highways

1. INTRODUCTION

1.1. General

The human civilisation over millenniums has resulted in the increased need of movement of men and materials. Transport of passengers and freight has developed into a major and vital sector and is indeed the backbone of the development of a society and hence a country with reference to its economy, technology, security and the overall growth. The road transport is perhaps the oldest and undoubtedly, the widely accepted and adopted mode of transport by the mankind. It is imperative that, for the full and proper development and advancement of a nation, an efficient road transport system in its place is essential. A well developed and maintained road transport sector functions as a catalyst in evolving the country's status.

The road transport is in great demand due to its many inbuilt and inherent advantages including its flexibility and reliability. In the changing scenario of globalisation and economic liberalisation a great deal of emphasis is laid on development of this infrastructure through construction of a dependable road network. Consequently, new construction and the upkeep of existing road network have assumed significance to a greater degree.

1.2. Growth of Road Network

There has been a manifold increase in road transport and the vehicle population in India, in the last few decades. The growth rate is tremendous, especially after the liberalised economic policies and developments in the industrial and agricultural sectors. The total length of road network which was only 0.4 million km during independence has grown by 9 times, to more than 3.5 million km now, in the 50 years period. The various categories of roads with their lengths forming the Indian road network are given below.

Length of Different Categories of Roads

Category of Road	Length, Million km
National Highways	0.06
State Highways	0.13
District Roads (MDR, ODR), Village Roads and Other Roads	3.12
Urban Roads	0.22
Total	3.53

Though, the National Highways constitute less than 2 per cent of the total network, they carry more than 40 per cent of total traffic. This importance is expected to increase further with the completion of the 'National Highways Development Project' which aims to provide international standard highways on Golden Quadrilateral and North-South and East-West Corridors. The total length to be covered on these corridors is estimated at 13,252 km.

1.3. Vehicle Growth and Damaging Effects

The growth of number of motor vehicles has witnessed a spectacular increase from nearly 0.3 million to 45 millions in a period of 50 years indicating a stunning jump of 150 times. Also, with introduction of new generation vehicles on roads, the load carrying capacity of the commercial vehicles has been enhanced. However, to meet the increasing demands of higher pay loads at minimum unit haulage costs, overloading of vehicles has been a common phenomenon on Indian roads. The legally permitted axle loads and gross vehicle weights have increased steadily. This has a significant implication on highway performance as the pavement structural design methods normally convert expected traffic load repetitions to a number of equivalent standard axle loads (ESALs). In the traffic data needed for designing and managing pavements, the final requisite is the total number of ESALs during the design period.

On an average, heavy commercial vehicles contribute nearly 80 per cent of ESALs imparted to pavement distress on highways. Actually, pavement deterioration is the result of the interaction of vehicle and environmental factors. The cost effective maintenance strategies, therefore, should take into consideration the impact of higher axle loads.

Also, at any given time, the structural and hence the functional condition of a pavement depends on the adverse effect created by ingress and presence of moisture. Water, to a great extent, can weaken subgrade and overlaying layers. This needs, an effective and efficient and well maintained drainage system to minimise the damage to road pavements.

1.4. Road Condition Scenario in India

The construction and maintenance of roads has become a gigantic task for road engineers, with the ever increasing demand for road transport. The existing road network has fallen greatly short of the required capacity and adequacy. To meet the demands, overstraining the existing infrastructure and the vehicle fleet, is followed and the result is a higher transportation cost. The majority of the roads in the country are deficient with regard to design, standards and geometrics and are, thus, responsible for long number of accidents, congestion, delays and ultimately higher vehicle operating costs. These may end up in an irreparable damage to economic growth rate.

It is of great concern to note that, the large network established at huge cost is showing signs of accelerated deterioration because of mainly two reasons :

i) Increased traffic and higher loads than permissible

ii) Shortfall in funds for construction and maintenance of roads

Due to the poor condition of roads, it is estimated that an annual loss of approximately over Rs. 6000 crores is resulted in VOC alone. The timely maintenance is missing due to many reasons, which otherwise could have minimised the losses to the exchequer. A rough estimate suggests that more than 50 per cent of the length of primary road network is in bad shape needing immediate attention. It should be borne in mind that for achieving the desired economic growth, the foremost requirement is to ensure a good and an effective road network.

2. SCOPE AND NEED

2.1. General

India has the third largest road network in the World. The entire network can be conveniently categorised as :

i) Primary Roads – Expressways and National Highways (NHs)
ii) Secondary Roads – State Highways (SHs) and Major District Roads (MDRs)
iii) Tertiary Roads – Other District Roads (ODRs) and Village Roads (VRs)
iv) Urban Roads – Roads in Urban Limits / Territory

Of late, a new category of roads under "Major State Highways" also has come into existence in some States, with specifying the geometric features of a State Highway equivalent to that of National Highways. Though, the intended purpose of any category of these roads is to provide satisfactory level-of-service to road users, the stated level-of-service may not be same in all the cases. The construction specifications, traffic, pavement strength, ancillary structures, adjoining facilities, etc. may differ in their characteristics among the various categories of roads. Accordingly, the structural and functional requirements and hence the maintenance needs also differ within these categories.

Construction of roads involves substantial investment and therefore proper maintenance of these assets is of paramount importance. An amount of nearly Rs. 30000 crores has been spent on road development upto the end of 8th plan. The road user cost, comfort and safety are influenced to a large extent by the quality and quantity of maintenance inputs. The large network of existing roads, built at huge expenses has started showing signs of premature failure due to cumulative effect of inadequate maintenance and structural inadequacy to meet the needs of increased traffic volume and loads.

However, the preservation of assets made out of public investment by timely upkeep and maintenance offers lucrative advantages, which include :

i) Reduced rate of deterioration and prolonged life of road infrastructure
ii) Reduction in vehicle operation costs
iii) Reduction in rate of accidents
iv) All weather, traffic worthy roads
v) Reduction in pollution released to environment by reduced wastage of fuel
vi) Savings on capital investment in restoration/reconstruction

The above advantages may benefit one or more segments of the society and hence the nation.

Despite recognising the need and usefulness of providing adequate funds for maintenance of roads, there has been a continuous shortage in its provision. It is established that :

i) Pavement maintenance expenditure constitutes a very small percentage of the total cost of the road transport system

ii) The total system costs are largely dominated by VOC only

Since VOC is significantly influenced by pavement condition, relatively small savings in pavement maintenance would result in wasting of more resources on the vehicle side. The gap between the actual allocation and the minimum requirements for maintenance over years has resulted in self-accumulation of deficiencies in road sector. Even through this deficiency can not be removed in one go an earnest attempt is required to be made now for providing sufficient funds for maintenance of roads. According to a World Bank Report (1987) "the developing countries (India is no exception) have last precious infrastructure worth billion of dollars through deterioration of roads. The cost of restoring these roads is going to be 3 to 5 times greater than what would have been for timely and effective maintenance". While road construction and maintenance consume a significant proportion of the national budget, the economic consequences of ignoring timely maintenance are to be seriously viewed.

2.2. Pavement Maintenance Management System

Pavement Maintenance Management System (PMMS) is a technical or operational methodology for managing or directing and controlling maintenance resources, in a scientific manner, for optimum benefits. It is a complex problem of matching of resources, time, materials, labour, equipment, funds, design and most of all decision making, whereas, Pavement Management System (PMS) consists of a comprehensive, coordinated set of activities associated with the planning, design, construction, maintenance, evaluation and research of pavements. A major objective of PMS is to assist the highway engineer in making consistent and cost effective decisions related to the construction, maintenance and rehabilitation of pavements.

The Pavement Maintenance Management System performs the following functions:

i) To identify projects, in need of M&R and to establish priorities
ii) Identification of the type of maintenance and/or rehabilitation required
iii) Requirement of type and timing of future M&R
iv) To minimise life-cycle costs or maximise benefits
v) To predict performance of pavements in future

The prime purpose of maintenance phase in a Pavement Management System is to determine the cost associated with providing various level-of-serviceability for any given pavement. This is an important feedback to planning, design and construction. The type and degree of maintenance can also influence the rate and serviceability loss for a pavement. It is clear that maintenance management requires careful planning and implementation, efficient reporting of maintenance practices and problems. Hence, maintenance management is primarily managing our resources to provide an agreed level-of-service.

2.3. Need for Development of Guidelines

It is found that the actual maintenance expenditure amount available is much less than what is required. The current maintenance practice in India is to provide the maintenance and rehabilitation strategies based on subjective judgement and engineering experience. The success of the outcome depends on the experience of the decision making highway engineer. Ironically, even if the engineer has a significant experience, presently analytical tools are generally not used in India to assist him in selecting the best strategy based on the economics of life-cycle costs. The principal causes for the deterioration of the roads and the ineffectiveness of different maintenance strategies often remain unevaluated due to non-availability of objective data base required for the analysis of various activities, such as, design, construction, maintenance, etc. Failure to recognise the importance of systematic management of pavements, risks not only part of the very significant resources spent on pavement maintenance, but also wasting far more resources subsequently in the form of higher vehicle operation costs and unit maintenance costs in the later stages of the pavement deterioration process.

There is a need for development of guidelines to devise methodologies for systematic data collection on the structural and functional performance of all categories of roads under varying climatic, traffic and environmental conditions and the data analysis to scientifically planning and judicious allocation of maintenance funds. The maintenance needs of different categories of roads are to be prioritised using appropriate tools and the accruing benefits of proper maintenance vis-a-vis the losses, on account of poor/deferred maintenance, need to be quantified.

2.4. Objectives and Scope

The main objective of this project is the formulation of guidelines for the maintenance management of primary, secondary and urban roads. The scope covered is as follows:

a) Review of the maintenance practices in India and identification of the deficiencies in the current practices

b) Review/appraisal of work done outside India and in India

c) Identification of data requirements for MMS

d) Development of methodology for data collection

e) Identification of equipment for data collection

f) Evolvement of a methodology for manpower requirements, equipment operation, calibration and periodicity of updating

g) Identification of requirements and software for data base and data elements

h) Hardware requirements and software requirements for data base development

i) Equipment and methodology for data collection on both functional and structural evaluation

j) Development of methodology for data analysis

k) Identification of organisational requirements

l) Determination of intervention levels for maintenance planing and level-of-service

m) Evolvement of maintenance strategies and techniques for optimization

n) Prioritization of maintenance strategies

o) Recommendations for dissemination of guidelines

3. REVIEW OF MAINTENANCE PRACTICES/ NORMS FOR PRIMARY, SECONDARY AND URBAN ROADS

3.1. General

The requirement of improved maintenance norms is a pre-requisite to ensure a smooth and safe transit of passengers as well as freight, with increased axle loads and adverse environmental conditions. However, due to inadequacy of funds as well as a poor maintenance, a large scale of dissatisfaction has resulted in especially from the segments, like, the truckers and the frequent road users. There is a general feeling that roads are not being maintained upto the desired level-of-service. The primary reason for causing dissatisfaction is that the Government has been struggling to provide bare minimum maintenance funds required to keep the roads open in traffic worthy condition. The norms as such do not provide for the criteria of level of satisfaction which could be catered to only under an improved financial support system. Another factor of great concern in maintenance is the fact that the majority of the road network system has not been structurally designed to withstand traffic over the 15-20 years design life. This deficiency leads to excessive maintenance costs, which may not in the long run provide a sustainable road network.

3.2. Concept of Performance Indicators/Maintenance Quality Levels

There is a large difference between the perception of the Government, the road administration and the actual road users on the quality levels to be achieved on roads. Efforts are being made all over the world to develop standards for maintenance quality levels to which roads must be maintained to provide the requisite level of comfort, convenience and safety to the road users. In economic terms, the maintenance of roads should be to such a level that the vehicle operating costs and accident costs are minimised. Environmental concerns are also being looked at to reduce the vehicle operating cost (VOC) and levels of emissions from road traffic. The measure of maintenance quality levels, which have been accepted in most of the developed countries, consist of measuring some of the following service conditions to determine a "Serviceability Index".

(a) Roughness
(b) Percentage cracking
(c) Rutting
(d) Skid resistance
(e) Potholes per kilometer
(f) Percentage defective bridge deck area

While proposing a desirable level-of-service, the needs of road users, road safety, etc. are to be duly considered. A setup desirable levels-of-service are given in the following table. The standards being proposed here would be equally effective in raising low levels of maintenance and in reducing high levels that are costly or unnecessary. It is also notable that all the National Highways/State Highways cannot be maintained to the highest level-of-service due to constraints of funds and may not be required to that level if the traffic requirements of the areas do not justify it. Accordingly, the maintenance program can be conveniently divided into three maintenance levels which are identified as level 1,2, & 3. Level 1 is the desired level that provides for highest level of comfort, convenience and safety. Level 2 is the level to which the road deteriorates from level 1 after two-three years of use before fresh maintenance is implemented. Level 3 represents the minimum level necessary to protect the investment and provide reasonable levels of safety. The suggested level-of-services based on measurement of roughness, cracking, rutting, etc. are given below :

SERVICEABILITY INDICATORS FOR ROADS

Sl. No.	Serviceability Indicator	Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1.	Roughness by bump integrator (Max. permissible)	2000 mm/km	3000 mm/km	4000 mm/km
2.	Potholes/Km (Max. Numbers)	Nil	2-3	4-8
3.	Cracking and Patch Repairs (Max. permissible)	5 per cent	10 per cent	10-15 per cent
4.	Rutting (20 mm) (Max. permissible)	1.0 per cent	1.5 per cent	2.5 per cent
5.	Skid Resistance (Skid number by ASTM-274) Minimum Desirable	50 SN	40 SN	35 SN
6.	Defective bridge deck area and bump at approach (Max. permissible)	Nil	10 per cent	15 per cent
7.	User Information	All road signs, km stones and road marking in good condition	Only major road signs, km stones, some road markings in good condition	Signs only for major destinations and km stones in fair condition

At present, most of the roads in the country come under Level 3 based on the current level of funding being provided for maintenance.

3.3. Upgradation of Maintenance Norms and Recommendations

Road sector in the country has witnessed a tremendous growth and change. The production of vehicles in the country has tremendously increased, the traffic intensities have increased beyond the expected limits, the freight and consequent axle loads have grown beyond the legal limits. Over and above, the expectations of users have also increased with the introduction of high-speed modern vehicles. The combined effect of all these aspects is the demand for properly maintained roads.

The maintenance activities have been divided into the following heads for the purpose of organisation of maintenance budgeting :

a) **Ordinary Repairs :** This activity involves routine maintenance, such as, maintenance of culverts, patch repairs, crack sealing, roadside drainage, repairing of shoulders, painting of highway signs and km stones, arboriculture and turfing, road marking maintenance of gang huts and store sheds, removal of litter, debris and dead animals and replacement of damaged retro-reflective signs, etc. The routine maintenance would need additional attendance to maintenance of medians footpath repairs street lights minor repair to fly-overs and subways, railings as well as removal of encroachments in urban areas and maintenance of breast walls/retaining walls, removal of slips and snow clearances, etc. in hill areas. The routine maintenance of bridges requires attendance to bearings, joints, wearing coat, railings, minor repair to sub-structure and super-structure as well as clearance of weeds, etc. in the river channels.

b) **Periodical Renewal :** This activity involves provision of renewal coat to the wearing surface at a predetermined frequency. This is done to safeguard the road crust and at the same time giving pavement a better riding surface. This treatment shall be carried out only with the help of mechanised equipments and in continuous stretch of at least 5 to 10 km. The cement concrete roads are not being provided with periodical renewal treatment and no provision has been made in the norms. However, depending upon their surface deterioration over a considerable period of time, the concrete roads are to be considered either for provision of flexible overlays to cover the damages and for improvement of riding quality or rehabilitated suitably under 'original' plan works. Provision for centre line markings and shoulder markings with thermoplastic paints has been made in the cost for Periodical Renewals and to be repainted as per PR cycle in case of NH/SHs only. For other categories, markings with ordinary paints under OR is to be done.

c) **Special Repairs :** This activity deals with urgent works of original nature, such as, minor improvement to curves, improvements to visibility, repairs to culverts, bridges, etc.

d) **Emergent Repairs :** This activity involves immediate repairs to roads affected by heavy rains/flood, cyclone, landslides, sand dunes, etc. to restore traffic.

It is pertinent to note that organisational structure of maintenance activities related to ordinary repairs has worked well in the past and it may be recommended that the same may be continued after updating to include all the new activities required to keep pace with time and development, till a scientific Maintenance Management System is placed in position.

3.3.1. Price zones: In ordinary repairs, the cost of material is about 62-67 per cent of the total cost. In periodical renewals the cost of material is 67-72 per cent of the total cost. The most sensitive item in the cost of material is the cost of stone chips/metal. Other items, like, bitumen, labour and equipment do not show much variation across the country. In view of this the cost of stone chips has been identified as the single parameter for dividing the country into six price zones, so that the cost of maintenance in any region can be quickly worked out if the price of stone metal is known. It needs to be clarified that these price zones have no linkages with any particular geographical location and it is also possible that more than one price zones may be applicable for any state or region depending upon the availability of stone metal and the leads involved. It is also notable that due to imposition of environmental restrictions on quarrying, the prices of stone metal have increased substantially in many areas and areas, which were earlier in a low price zone, may now be shifted to a high price zone.

Accordingly, six zones are decided on the basis of cost of stone aggregates. In hilly areas, the cost of material and labour is more than other regions due to climatic conditions and higher cost of cartage. Therefore, to cater for the requirement of hilly areas, one more zone VIA has been added. The price in hilly areas is generally observed to fall in price zones from V, VI and VIA. The details of price zones and of the BASIC STONE METAL COSTS in each of the zones are tabulated as below :

Zones	I	II	III	IV	V	VI	VIA **
* Range of cost of stone chips in Rs. per cum	280-350	350-400	400-500	500 580	580-660	660-740	740-860

* Indicates the cost of stone metal in different zones

** Indicates the high price range valid only for hilly areas

3.3.2. Traffic ranges : The traffic volume on both the single and double-lane roads in the country have increased beyond their normal capacities. This has resulted

in single-lane roads carrying more than 1500 commercial vehicles a day and two-lane roads carrying more than 4500 commercial vehicles a day. This concentration of traffic has considerably reduced the life of surface treatment, which were being provided earlier. For such heavy traffic specifications, like, single coat surface dressing would be totally inadequate and may need renewal at higher frequency. In the case of two-lane roads where traffic is more than 4500 commercial vehicles per day, nothing short of bituminous concrete can serve the purpose. It is, however, notable that where 4-laning is done, the traffic in each of the two-lanes would get reduced to half and at that stage perhaps premix carpet could also serve the purpose in the initial years. But, it is recommended that where the existing surface is bituminous concrete, it should only be renewed with the same treatment or a better treatment. The traffic ranges considered are :

Traffic Ranges in CVD	< 150	150-450	450-1500	1500-4500	>4500

3.3.3. Norms for national/state highways: The National Highway network throughout the country and State Highway network within the respective States constitute the backbone of the road transport network in the country. As this category of roads caters to high intensity traffic (including heavy axle loads), the same are necessary to be maintained as all weathered roads to the extent possible. These roads are eligible for a higher level of maintenance and it is required to recommend separate norms for the same.

3.3.4. Norms for MDR/ODR/VR: The major constituents of the road network in the country are the roads falling in the category of MDR/ODR/VR. These roads generally carry local traffic as they are exposed to road traffic of lesser intensity, the maintenance requirements are different from the one as mentioned above. Therefore, separate norms for this category of roads are recommended.

3.3.5. Norms for urban roads: The urban roads have unique features, which need to be accounted for in the norms so as to ensure their maintenance in right perspective. These features are pedestrian underpasses, flyovers, traffic signals, overhead signs, raised footpaths, railings, service lanes street lights, etc. Even removal of dead animals and litter and garbage has become a perennial activity. The urban roads, are exposed to continuous flow of traffic and keeping in view the limited working hours for maintaining such roads, it is required that a high level of mechanisation should be adopted on these roads. Therefore, separate norms for urban roads may by adopted.

3.3.6. Norms for hill roads: The hill roads have number of peculiar features which are not experienced in the roads in plain or rolling terrain. These roads besides being susceptible to landslides/snow fall have features, like, steep gradient limited road

land width, steep side slopes, slip zones, etc. Also, the hill roads have a large number of structures, like, retaining walls/breast walls parapet walls, cross drainage culverts, etc. which require continuous maintenance for ensuring safety and serviceability of these roads. In addition, the condition of roads in some of the hilly areas deteriorates further due to seismic effect and cyclones. In hilly areas, there is an additional requirement of heavy machinery (i.e. wheel dozers, track dozers, compressors, etc.) vehicles, gangs of organised labour are required to be deployed for opening of roads within a minimum time in case of emergent situations, like, blockade due to slips snow or road breaches due to erosion. In such areas it is also necessary to consider the cost of keeping these resources readily available to meet these emergent needs. The cost of maintaining such resources would depend upon the norms set for the maximum permissible hours/days at a stretch for which National Highways/State Highways can be kept closed. As such, in such areas separate provision will have to be made over and above the usual norms.

3.4. Maintenance Norms Recommended by MoRT&H

Due to the increasing need of a review of the existing maintenance norms and laying of revised norms as applicable to the road network in India, in 1997 the Ministry of Road Transport & Highways (MoRT&H) had set-up a Committee. After carrying out detailed deliberations on all the factors relevant to maintenance requirements and the present day needs of rapidly growing traffic, the Committee set-up by MoRT&H for the purpose have worked out norms for Normal Roads (National Highways/State Highways, Major District Roads/Other District Roads/Village Roads), Urban Roads and Hill Roads based on traffic volumes, price zones and climatic conditions.

3.4.1. Norms for national highways/state highways: For National Highways/ State Highways, maintenance norms have been calculated for double-lane (7.0 m) with 1.5 m wide paved shoulder per year per km for BT surface. The Committee recommends that on NH/SH, WBM surface should be black topped on priority, therefore, no norms are recommended for WBM surfaces in case of NH/SH.

a) Details of Total M&R Costs

Zonewise summary and details of total maintenance and repairs costs are given below:

Zonewise summary of total M&R costs per year in Rs. per km double-lane (7.0 m) with 1.5 m paved shoulder of NH/SH with reference to traffic and terrain-

Figures in Rupees

Category	Traffic in CVD				
	> 450 CVD	450-1500 CVD	1500-4500 CVD	<4500 CVD	<4500 CVD
	BT Surface	BT Surface	BT Surface	BT Surface	Cement Concrete
Zone – I					
Normal	328724	406429	455807	621503	138165
Urban	476673	529271	588326	793250	186395
Zone – II					
Normal	337750	418039	468363	640415	148110
Urban	489565	543270	603362	816128	196340
Zone – III					
Normal	344567	427218	478575	655801	157665
Urban	500249	554332	615555	834685	205895
Zone – IV					
Normal	353974	434688	493886	679047	167220
Urban	515951	563127	633946	862858	215450
Zone – V					
Normal	362021	452518	506876	698719	170405
Urban	529465	584931	649518	886661	218635
Hills	689633	754145	842058	927986	—
Zone – VI					
Normal	369591	463545	519402	717647	176775
Urban	542424	598232	664509	909535	225005
Hills	707634	772550	862628	952619	—
Zone – VI A					
Hills	735087	801916	890511	988264	—

b) Details of Ordinary Repair (OR) Costs

Zonewise summary and details of Ordinary Repair Costs for various zones are given below:

Zonewise Summary of OR costs for NH/SH in Rs. per km double-lane (7.0 m) with 1.5 m paved shoulder per year for each zone

Figures in Rupees

Category	Zones	<450 CVD	450-1500 CVD	1500-4500 CVD	> 4500 CVD	
		BT surface	BT surface	BT surface	BT surface	CC surface
Grand total (Normal)	Zone-I	78049	83064	91268	98028	106281
Grand total (Urban)		108549	120164	128368	135128	143381
Grand total (Normal)	Zone-II	79157	84644	93300	100371	113931
Grand total (Urban)		109657	121744	130400	137471	151031
Grand total (Normal)	Zone-III	80271	85907	95057	102450	121281
Grand total (Urban)		110771	123007	132157	139550	158381
Grand total (Normal)	Zone-IV	81736	87579	97360	105172	128631
Grand total (Urban)		112236	124679	134460	142272	165731
Grand total (Normal)	Zone-V	83038	89064	99407	107592	131081
Grand total (Urban)		113538	126164	136507	144692	168181
Grand total (Hills)		100938	106964	117307	125492	
Grand total (Normal)	Zone-VI	84339	90550	101455	110012	
Grand total (Urban)		114839	127650	138555	147112	135981
Grand total (Hills)		102239	108450	119355	127912	173081
Grand total (Hills)	Zone-VI-A	105367	111807	123414	132437	

c) Details of Periodical Renewals

Zone wise Summary and details of Periodical Renewal costs are given below:

Zonewise Summary of OR costs for NH/SH in Rs. per km double-lane (7.0 m) with 1.5 m paved shoulder per year for each zone

Figures in Rupees

Category	Zones	<450 CVD	450-1500 CVD	1500-4500 CVD	> 4500 CVD
		BT surface	BT surface	BT surface	BT surface
Normal	Zone-I	174816	229574	259352	380052
Urban		258122	286968	324190	475064
Normal	Zone-II	180651	236925	266980	392255
Urban		266931	296156	333725	490319
Normal	Zone-III	184780	242722	273078	402012
Urban		274036	303402	341347	502515
Normal	Zone-IV	190552	246797	282552	417172
Urban		284650	308496	353190	521464
Normal	Zone-V	195440	259026	290497	429884
Urban		293743	323783	363122	537355
Hills		391658	431711	484162	537355
Normal	Zone-VI	199961	266023	298085	442024
Urban		302410	332529	372606	552530
Hills		403214	443372	496808	552530
Hills	Zone-VI-A	419695	460990	512666	573465

NB:The above cost for periodical renewal includes provision of Rs.2.00 lakhs for Road marking with thermoplastic paints (Center Line-Continuous shoulder line) divided by cycle of renewal to provide for per year cost of road marking.

d) Specifications for Renewal

Renewal Interval for National Highways/State Highways

Type of Treatment/ Category of Road	Traffic Intensity in CVD	MR-I	**SD-I/ SD-II	PC+SC	20 mm MSS	25 mm SDBC	25 mm BC	@40 mm BC
NH/SHs (Normal)	>4500	—	—	—	—	—	5/4*	5/4*
	1500-4500	—	—	—	—	5/4*	5/4*	—
	450-1500	—	—	—	5/4*	5/4*	—	—
	<450	—	—	5/4*	5/4*	—	—	—
NH/SHs (Urban)	>450	—	—	—	—	—	4/3*	4/3*
	1500-4500	—	—	—	—	4/3*	4/3*	—
	450-1500	—	—	4/3*	4/3*	4/3*	—	—
	<450	—	—	4/3*	4/3*	—	—	—
NH/SHs (Hilly)	>1500	—	—	—	—	4/3*+	4/3*	4/3*+
	450-1500	—	—	—	4/3+	4/3*+	4/3*+	—
	<450	—	—	5/4*	5/4*+	—	—	—

Note : (A) * Indicates reduced life of treatment due to high rainfall, i.e., >3000, mm.
(B) + Indicates reduced life due to higher altitude, i.e., >2000 Mts.
(C) ** This treatment of SD-I is to be used under condition of severe resource crunch only.
@ For exceptionally heavy traffic corridors

3.4.2. Norms for MDR/ODR/VR: For MDR/ODR/VR maintenance norms have been calculated for double-lane (7.0 m) without shoulders per year per km for BT surface as well as WBM surface. The Committee recommends that WBM or gravel surfaces may be provided for stretches carrying traffic <150 CVD in normal area only and all other stretches carrying traffic >150 CVD should be at least black topped.

- Norms have been recommended for Normal, Urban and Hilly areas
- Abstract and details of costs of Total M&R, OR and PR for various zones have been given in the following paragraphs.

a) Details of Total M&R Costs

Zonewise summary and details of total maintenance and repairs costs are given below:

Figures in Rupees

Category	Zones	Traffic in CVD				
		<150		150-450	450-1500	>1500
		BT	WBM	BT	BT	BT
Normal	**Zone-I**	160927	132687	170383	202997	227095
Urban		208924	220290	226119	266069	297100
Normal	**Zone-II**	164520	145388	175859	208824	233057
Urban		213094	239365	232765	273132	302449
Normal	**Zone-III**	167762	158931	180653	214291	238749
Urban		216882	259508	238616	279807	309389
Normal	**Zone-IV**	174095	181794	188333	224441	244866
Urban		224280	283708	247931	292178	316683
Normal	**Zone-V**	178486	190168	194281	231792	257119
Urban		229387	307182	255138	301113	331718
Hills		216170	248702	252549	278229	368871
Normal	**Zone-VI**	182777	205051	199704	238820	264426
Urban		234374	329759	261689	309645	340571
Hills		221688	267128	259732	285691	378553
Hills	**Zone-VI-A**	229812	284595	271935	297814	391254

b) Details of Ordinary Repair (OR) Costs

Zonewise summary and details of Ordinary Repair Costs for Zones IV and VI are given below:

Summary of MDR/ODR/VR for Two Lane/km.

Figures in Rupees

Category	Zones	Traffic in CVD				
		<150		150-450	450-1500	>1500
		BT	WBM	BT	BT	BT
Normal	**Zone-I**	36440	29450	37063	39486	42298
Urban		55440	48450	56063	58486	61298
Normal	**Zone-II**	36965	31775	37654	40143	43027
Urban		55965	50775	56654	59143	62027
Normal	**Zone-III**	37340	34475	38076	40612	43548
Urban		56340	53475	57076	59612	62548
Normal	**Zone-IV**	38090	42050	38920	41550	44590
Urban		57090	55800	57920	60550	63590
Normal	**Zone-V**	38690	39350	39595	42300	45424
Urban		57690	58350	58595	61300	64424
Hills		50090	50750	50995	53700	56824
Normal	**Zone-VI**	39290	41825	40270	43051	46257
Urban		58290	60825	59270	62051	65257
Hills		50690	53225	51670	54451	57657
Hills	**Zone-VI-A**	51365	54950	52430	55295	58595

c) Details of Periodical Renewal (PR) Costs

Summary of PR for MDR/ODR/VR for Two-Lane (7.0 m)/km.

Figures in Rupees

Category	Zones	Traffic in CVD				
		<150		150-450	450-1500	>1500
		BT	WBM	BT	BT	BT
Normal	**Zone-I**	82765	68837	89146	110882	125921
Urban		99319	114728	111433	138602	158776
Normal	**Zone-II**	84902	75920	92612	114542	129608
Urban		101882	126533	115765	143177	162009
Normal	**Zone-III**	86928	83252	95741	118122	133303
Urban		104314	138753	119677	147653	166629
Normal	**Zone-IV**	90869	92612	100586	124703	136792
Urban		99130	154354	114302	155878	170990
Normal	**Zone-V**	93522	101515	104317	129397	145035
Urban		112226	169192	130396	161746	181293
Hills		104317	126894	129397	145035	206655
Normal	**Zone-VI**	96100	110065	107659	133853	149614
Urban		115320	183441	134573	167316	187018
Hills		107659	137581	133853	149614	212738
Hills	**Zone-VI-A**	112786	148332	141809	157429	220872

d) Renewal Interval for MDR/ODR/VR

Type of Treatment/ Category of Road	Traffic Intensity in CVD	MR-I	**SD-I/ SD-II	PC+SC	20 mm MSS	25 mm SDBC	25 mm BC
MDR/ODR/VR (Normal)	>1500	—	—	—	—	5/4*	5/4*
	450-1500	—	—	—	5/4*	5/4*	5/4*
	150-450	—	—	—	5/4*	5/4*	—
	<150	5/4*	5/4*	5/4*	—	—	—
MDR/ODR/VR (Urban)	>1500	—	—	—	—	4/3*	4/3*
	450-1500	—	—	—	4/3*	4/3*	—
	150-450	—	—	4/3*	4/3*	—	—
	<150	3	—	4/3*	4/3*	—	—

Type of Treatment/ Category of Road	Traffic Intensity in CVD	MR-I	**SD-I/ SD-II	PC+SC	20 mm MSS	25 mm SDBC	25 mm BC
MDR/ODR/VR (Hilly)	>1500	—	—	—	—	4/3*+	4/3*
	450-1500	—	—	—	4/3+	4/3*+	4/3*+
	150-450	—	—	5/4*	5/4*+	—	—
	<150	4/3*					

Note :
A) * Indicates reduced life of treatment due to high rainfall i.e. >3000 mm.
B) + Indicates reduced life due to higher altitude, i.e. >2000 Mts.
C) ** This treatment of SD-I is to be used under condition of severe resource crunch only.

e) Percentage of Labour, Material and Machinery

Category	Ordinary Repairs			Periodical Renewal		
	Labour	Material	Machinery	Labour	Material	Machinery
NH/SH	28	66	6	5	70	25
MDR/ODR/VR	30	67	3	10	72	18

3.4.3. Conversion factor: Maintenance norms for NH, SH, MDR, ODR and VR have been calculated for double- lane road (7.0 m) are given in paras 3.4.1 and 3.4.2. To find out the maintenance cost of lane widths other than standard width of two-lane i.e. 7 m, the conversion factors given below are to be adopted.

(a) For National Highways/State Highways

Reference cost taken for two-lane (7.0 m) with 1.5 m wide shoulders			
Ordinary Repairs			
S. No.	**Item**		**Factor**
1.	Two-lane without shoulder		0.90
2.	Single-lane	Without paved shoulder	0.56
		Paved shoulder	0.625
3.	Inter-mediate lane (5.5 m wide)	Without paved shoulder	0.68
		Paved shoulder	0.75
4.	Four-lane with divided carriageway	Without paved shoulder	1.53
		Paved shoulder	1.70
5.	Four-lane with divided carriageway and service lane on either side	Without paved shoulder	2.0
		Paved shoulder	2.2
	Periodical renewals	To be calculated in proportion to the area covered for various category of lanes	

N.B. In calculated Cost of PR for Two-lane with paved shoulder, an amount of Rs. 2.0 lakhs for road marking with Thermoplastic Paint (for Centre line and continuous shoulder line on both sides) has been added to treatment cost. Thus, total cost has been divided by the renewal cycle to get per year cost of renewal with road marking. For two-lane without shoulder, instead of Rs. 2 lakhs, only Rs. 20,000/- are to be added to the treatment cost as only centre line is to be marked.
Flood damage repairs : 15 per cent of (OR+PR) in normal and urban areas and 20 per cent of (OR+PR) in hills
Special repairs : 15 per cent of (OR+PR) in normal and urban areas and 20 per cent of (OR+PR) in hills

(b) For MDR/ODR/VR

Reference cost taken for two-lane (7.0 m) without shoulders			
	Ordinary Repairs		
S. No.	**Item**		**Factor**
1.	Single-lane	Without paved shoulder	0.625
		Paved shoulder	0.70
2.	Inter-mediate lane (5.5 m wide)	Without paved shoulder	0.75
		Paved shoulder	0.83
3.	Four-lane with divided carriageway	Without paved shoulder	1.70
		Paved shoulder	1.87
Periodic renewals			
Cost of PR to be calculated in proportion to the area covered for various category of lanes			
Flood damage repairs : 15 per cent of (OR+PR) in normal and urban areas and 20 per cent of (OR+PR) in hills			
Special repairs : 15 per cent of (OR+PR) in normal and urban areas and 20 per cent of (OR+PR) in hills			

3.4.4. Flood damage repairs (FDR): Every year some part or the other of the country, the road network is affected by floods and provision has to be made for repairs of damages and restoring these Highways to at least pre-flood condition. States, like, Andhra Pradesh and Orissa, which are prone to be hit by cyclonic storms have reported that expenditure upto 65 per cent of the maintenance budget provided as per norms are required for flood damage repairs. Director General (Border Roads) have reported that up to 25 per cent of the maintenance budget is used for flood damage repairs. Provision will have to be made for flood damage repairs on case to case basis for actual cost of restoration. The Sub-Committee for urban roads recommended that 12.5 per cent of (OR+PR) may be kept for FDR. Keeping in view overall considerations, Committee recommends that 15 per cent of (OR+PR) may be kept for FDR in normal and urban areas and 20 per cent for hills for all category of roads.

3.4.5. Special repairs (SR): The funds required for special repairs vary from State to State and depend upon the condition of the road network. The Committee after due deliberations recommended that 15 per cent of (OR + PR) should be earmarked for special repairs in plan/rolling terrain and urban areas and 20 per cent in hilly areas.

3.4.6. Premium for special conditions:

a) **Hill roads:** The following increase/deduction are recommended for the items covered under the ordinary repairs for price zones applicable to the hilly areas.

For areas having rainfall less than 1500 mm	Deduction by 15 per cent
For areas having rainfall more than 3000 mm	Increase by 25 per cent
NB: No deduction should be made in high altitude (Greater than 2000 m) areas even if the rainfall is less than 1500 mm.	

b) **Black cotton soil areas:** increase by 10 per cent

For routine maintenance activities under ordinary repairs.

3.5. Additional Provisions of Funds

3.5.1. For the use of modified bitumen: Investigations in India and countries abroad have revealed that properties of bitumen and bituminous mixes can be improved to meet requirements of pavement with the incorporations of certain additives or a blend of additives. These additives are called Bitumen Modifiers and the bitumen treated with these modifiers is known as Modified Bitumen. Modified Bitumen is expected to give 50 to 100 per cent higher life of surfacings depending upon degree of modifications and type of additives used.

The guidelines contained in IRC:SP:53 for use of bitumen modifiers may be followed. On experimental basis, Ministry issued a circular to use bituminous modifier in 10 per cent of National Highway length to be covered under renewal/resurfacing every year. On the basis of experience gained over the years regarding economy in use of bitumen modifier over years, more length of National Highways/State Highways may be covered in the years to come.

The Committee recommends that for estimate purposes, 10 per cent increase in the cost of periodical renewal may be considered to account for the cost of bitumen modifier.

3.5.2. For the requirement of hilly areas

i) Semi-Permanent Timber (SPT) Bridges

In the North-Eastern region and a few pockets of certain States, there are a number of SPT bridges which are yet to be replaced by permanent RCC bridges. Due to socio-economic growth in the region some industries have already come up with the result that there will be more generation of vehicular traffic and hence these timber bridges will have to be replaced by permanent bridges gradually as per availability of plan funds.

Lumpsum provision for the maintenance of bridges is not considered to be adequate to cover the maintenance of SPT bridges. For Assam, considering 5 running meter of SPT bridges per km of road, unit cost of maintenance per km works out to be Rs.14,500/-.

ii) Bridle Roads

Bridle roads are additional category of roads in hill area. They serve village and habitants in the remote, under-developed areas at varying altitudes. Bridle roads are not motorable roads and have steeper gradients for connecting villages and places and are used for pedestrians and animal transport. During rains, these are heavily damaged in the form of slips, erosion, etc. and have to be maintained. A provision of Rs.14000/- to Rs.16000/- per km is proposed for maintenance of such roads. The rate of maintenance shall be on the basis of actual requirement in case of roads which require snow clearance of more than one metre.

iii) Foot Bridges

In addition to permanent and SPT bridges on hill roads, a number of foot bridges are also constructed across the streams in remote areas. These are also required to be maintained and a separate provision @ Rs.1000/- per metre shall be needed.

3.6. Maintenance Practices for Road Networks of Different Categories in Some States

Road maintenance has, thus, far been considered unpredictable and therefore very little effort is made towards planning or scheduling of maintenance works. As discussed earlier, the expectations and functions from different categories of roads are different and so are the construction and maintenance levels. The maintenance of primary roads, apart from routine maintenance may demand regular renewals and strengthening, whereas, in case of urban roads routine maintenance alongwith thin resurfacings may be more frequently required.

The condition of roads in India, in general, is far below the satisfactory mark. Road

maintenance plays an important part by serving the two fold purpose, i.e. i) immediate improvement in condition and ii) retardation in the rate of deterioration. The current maintenance practices are adhoc and not based on the results of any scientific study and are depending on personal experiences and judgements, and thus are subjective. Funds given for maintenance grants are meager and far short of the requirements. The periodic upkeep of existing roads assumes considerable importance in the context of shortage of funds. Maintenance being a cost-effective option, prolongs the life of pavements and reduces the vehicle operation costs.

Recently, awareness towards maintenance roads, based on logical and scientific systems, is increasing, and agencies involved are looking out for "Pavement Management Systems" that are either developed or adopted for their conditions. Some of the States are having major corridors connecting to most of the other parts in the country. These States also have geographically a key position and possess good resources, thereby resulting in faster development of industrial and commercial activities. In such cases the service expected by the road user is to construct and maintain the roads in a scientific manner. Efforts made in this direction by certain States, like, Maharashtra, Gujarat are worth mentioning. On the other hand, some other States, like, UP and Bihar are not able to cope up with the situation because of resource constraints and other problems.

The maintenance practices adapted in the States of Gujarat, Maharashtra, Uttar Pradesh and Uttaranchal are discussed in the following sections.

3.6.1. Gujarat: The existing road maintenance norms in Gujarat, are in general, governed by a resolution No. MNR-1183/D 18.12.86 adopted by the Govt. of Gujarat. The maintenance norms are based on per km length of road to be maintained which are derived from the recommendations of the 8th Finance Commission Report and are, however, subject to availability of funds. The rates adopted including the amounts needed for ordinary repair and periodic repairs (known as current repairs and special repairs respectively, in Gujarat) are given below :

Category of Roads	Rate
I. Highways – BT	
a) Single-Lane	18,500-00
b) Double-Lane	23,500-00
II. Other Roads	
a) Earthen	6,500-00
b) Gravel	11,500-00
c) WBM	11,500-00
d) BT	16,000-00

While both State R&B Divisions and Panchayat Divisions are responsible for road maintenance, the former look after maintenance of the majority of State Highways and the latter take care of bulk of Major District Roads, Other District Roads and Village Roads. The breakdown of road length covered by both R&B Divisions and Panchayat Divisions are as under (as per 1994 data)

Division	Length in km				
	SH	MDR	ODR	VR	Total
State R&B	19,103	1,473	546	517	21,639
Panchayat	287	18,564	9,621	16,561	45,033
	19,390	20,037	10,167	17,078	66,672

The budget requirements are formulated by the divisions taking into consideration the lengths and respective norms for different categories of road. These are then compiled for making projections in the budget estimates for the State roads as a while. However, the actual budget allocations depend upon the overall financial conditions are resources available for the year.

The total amount allocated for maintenance of roads are commended to be broken as under, as per 8th Finance Commission :

Ordinary repairs	35 per cent
Surface renewals	50 per cent
Special repairs and minor flood damage repairs	15 per cent

However, in normal practice, in Gujarat, the maintenance allocation is divided into only two parts, *viz.*, 35 per cent for ordinary repairs and remaining 65 per cent for periodic repairs.

In general practice of ordinary repairs, engineers at various levels make road inspections at different intervals and work instructions are given by concerned DEE/S0 to work assistant and is carried out using labour gangs. The work or tasks attended by gang labour force are :

i) Patch repair
ii) Pavement edge repair
iii) Removal of excess vegetation
iv) Repair of shoulder
v) Cleaning of culvert and bridge opening and minor repairs
vi) Painting of structures and street furniture
vii) Traffic surveys

Though, many of the maintenance and repair works are the responsibility of departmental task force-in-charge of ordinary repairs, the permanent labour gang constituting the task force is reportedly less productive and highly costly. Thus, the allocated maintenance funds, may not be expected to be efficiently and effectively utilised for a meaningful purpose.

The periodic renewal works are, however, normally carried out through contracting by qualified contractors who have required expertise and equipment.

A detailed inspection of the road for works to be done in following year is completed by prior to year end by the AE and then by the year end by EE/SE. In the following financial year the list of roads is prepared by April, taking into account the work done till March for the previous financial year and their liability spread beyond and April for the current financial year. The calculation for sanction given for periodic renewals is made as following:

Grant available in the financial year	$= X_1$
Liability of previous financial year	$= X_2$
Amount available for fresh work during the financial year	$= X_1-X_2$
Sanction given for periodic renewals in the financial year	$2 (X_1-X_2)$

The periodic renewal works are invariably carried out using material from not mix plant located within a reasonable haulage distance.

3.6.2. Maharashtra: In the State of Maharashtra, the norms for maintenance and repairs of roads are adopted in 1978, based on the recommendations of a Committee set-up for the purpose by a resolution No. RDS/1978/52/DSK-5/ 11.02.76. The rates in the norms are approved per km length of the road. The various items of works which are required to be considered include ordinary repairs, periodic renewals, special repairs, flood damage repairs, maintenance and repair of major bridges.

For ordinary repairs the expenditure are made on three items, viz., road gangs for maintenance, patch repairs and side shoulder repairs. However, some maintenance works of bridges that may fall under special repairs, but need extra attention are put under separate norms. Ordinary repairs are of the nature of routine maintenance and are got executed generally through the departmental labour.

The present norms and the norms proposed for ordinary repairs, by a group set-up by the Govt. of Maharashtra for the purpose, in 1989 are given below :

Category of Road	Present Norms Rs. per km	Proposed Norms Rs. per km.
SH	4,500-12,450	25,600-38,200
MDR	4,350-6,100	21,050-30,100
ODR	3,700-5,000	20,300-20,650
VR	3,000-4,150	19,125-20,300
Unsurfaced Road	4,150-8,000	10,450

The suggested minimum maintenance norms are relevant only if the road to be maintained is of required structural adequacy which unfortunately is not so in many cases. Inadequate crust may lead to failure. Strengthening such stretches through original works is recommended. The norms for periodical renewals and special repairs are as follows:

Category of Road	Periodic Renewals	Special Repairs
State Highway (BT)	17330	6000
MDR	13798	3000
ODR	7970	800
VR		

These norms are the approved norms of MOST, in 1988 for consideration of 9th Finance Commission. The rates for single-lane carriageway, as given, are to be appropriately increased for intermediate and double-lane roads, as per suggested guidelines of the MOST. However, the maintenance works are taken-up depending upon funds allocation.

3.6.3. Uttar Pradesh and Uttaranchal: Uttar Pradesh, now divided into two parts politically and geographically, *viz.*, U.P. and Uttaranchal, has been following the guidelines for maintenance of roads as stipulated under para 407(a) of PWD Manual of Orders. Accordingly, A.R. estimates are prepared in each division by 15th January to cover next financial year vide GOI No.2922C/23 Sa-Ni-Annual-102C/74/26.12.75.

The distribution of maintenance expenditure on different parts of a road, by type of its surface is shown in the following Table.

Sr. No.	Item	Water Bound Macadam (WBM)	Painted	Cement Concrete
A	A travelled way surface (Patch repair work will not exceed 10 per cent of grant)	75	70 (60+10)	20
B	Shoulder – patries	10	10	60
C	Drainage-Ditches, culverts	2	3	7
D	Roadside – Jungle clearance erosion control, vegetation footpath, etc.	3	2	3
E	Traffic service guard rail signals	2	2	2
F	Clearance of ships-fallen treets and other obstruction	2	2	2
G	Bridges, superstructure, sub-structure, stream bed signs'	5	10	5
H	Special services: load limitations, detours, diversions, public relation, etc.	1	1	1
		100	100	100

Note: Effort should be made to repaint 25 per cent of the total kilometerage in the division if funds are available. Above distribution is subject to the instructions issued by Engineer-in-Chief from time to time.

In the maintenance of roads, with reference to travelled way, the repairs to large and extensive surface failures by scarifying, reshaping and adding new materials if necessary and is varied to soil, climate, location, materials and traffic.

The shoulders or patries are suggested to be covered for patches, properly dressed and rammed for proper slope and if required a stabilization is also suggested.

The drainage items are viewed as preventive measures for safety and convenience. Hence, periodical cleaning of ditches and culverts is recommended. Also, adequate cross-drainage is suggested to prevent the damage caused by water logging.

The roadside maintenance stipulates prevention of erosion of slopes, embankment and roadside area by rounding and flattening of affected areas, seeding, sowing and planting trees and vegetation.

The other important maintenance measures include safety services, clearing of slips, repairing of bridges, etc. and special service.

Because of hill roads in some districts having Irish bridges/causeways, special attention is recommended. Safety signs, use of lanterns and flags for signalling, etc. are suggested.

3.7. Deficiencies in Current Maintenance Practices

- The current maintenance and rehabilitation measures for pavements are based on subjective judgment and past experience of the road engineers only.
- Even if the engineer responsible for making decisions has a significant experience base to draw up the maintenance strategies, there are no available analytical tools for use by the highway agencies to assist the practicing highway engineers in selecting the best strategy based upon economics of 'life cycle cost.'
- The principal causes of pavement deterioration are left uninvestigated due to lack of data on design, construction and maintenance aspects of pavements.
- Because of limited resources availability at a given point of time, the practice of stage construction is adopted. The pavements are normally designed for an initial service life of about 10 years and then strengthening is provided as the traffic demand increases.
- Allocation of funds for maintenance does not exceed 50 per cent of the normal requirements of roads. Consequently, the gap between the allocation and requirements has been accumulating over the years.

- Apart from funds, weak planning, poor scheduling and monitoring of maintenance operations, inherent deficiencies in the crust thickness and lack of attention to drainage have contributed much towards accelerated deterioration of road networks.
- Lack of proper coordination between different components of road maintenance work and different organizations.
- The specifications laid for materials and machinery are seldom followed.
- Bituminous materials/mixes are not properly designed and produced for maintenance.
- The surface is not checked and corrected for cross slope and undulations, to make-up the same.

4. REVIEW/APPRAISAL OF GLOBAL DEVELOPMENTS

4.1. Work Done Abroad

In the early seventies, the phrase "Pavement Management System" began to be used by researchers to describe the entire range of activities involved in providing and maintaining pavements. At the same time, initial operational systems were also developed. Since then, the following factors have provided great impetus for growing interest in PMS development.

- Increasing budgetary constraints in relation to maintenance needs
- Recognition of direct effect of pavement condition on road user costs
- Awareness of social and environmental values affected by road transport and road surface characteristics
- Advances in the development of pavement technology
- Increased capacity in pavement condition monitoring through advanced measuring equipment
- Advances in computers and information systems
- General growth in awareness of management methods

Presently, many highway authorities in developed countries are using a systematic and objective method to determine pavement condition and programming maintenance in response to observed conditions, as budget permits. In many of the developing countries, PMS is in various phases of working process with diversified approaches as per the respective needs and problems of each country.

4.1.1. United States of America (USA): The concept of PMS took root in USA during the recent era of austere budgets. The first PMS model was developed by the Washington State Department of Highways in the mid seventies. This model consisted of development of performance prediction model and a cost model based on a databank of information collected in Washington over a period of 6 to 8 years. Two specific types of performance models were considered – the regression model and Markov Chain model and the latter was selected for use as it was found out to be most reasonable procedure at that time. The cost model included considerations of routine maintenance costs, construction costs, and even road user costs. The pavement management system framework provided an objective procedure for comparing the performance and cost models of several maintenance strategies and selecting the strategy that would be most economical for any designated time period.

Since the development of PMS by Washington, various state departments of transportation have developed their own PMS methodologies suitable to their own needs and requirements. The Arizona Department of Transportation reported savings to the tune

of $2000 million over a period of five years as a consequence of successful implementation of PMS programme to optimize pavement rehabilitation expenditure. The State of Iowa has developed an Iowa Pavement Management Program (IPMP) to support both project level and network level PMS conducted by local and regional governments and the Iowa Department of Transportation.

The Pavement Management System (called PMS-III) developed and implemented for the Ohio Department of Transportation (ODOT), is a network level system that can prescribe optimal maintenance and rehabilitation actions and the required budget for each year of a 6-year planning period. On the basis of present network condition, and a deterministic prediction model, PMS-III forecasts future network condition, the rehabilitation needs an associated budget. The optimal maintenance policies recommended by this pavement management system are based on maximizing the preservation of pavement investment for a given annual budget or on minimizing the cost of maintaining the network condition at a given performance level. Fig. 4.1 shows the conceptual framework for Ohio PMS-III.

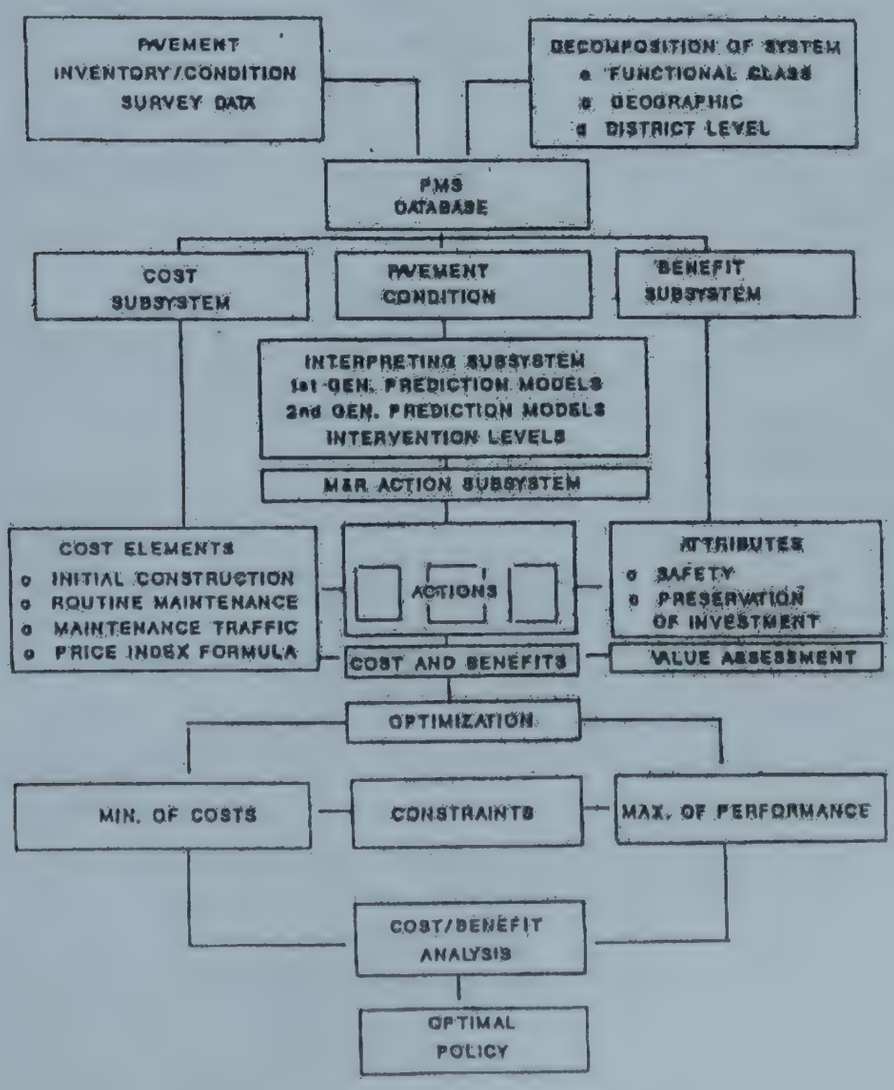


Fig. 4.1. Conceptual Framework of Ohio PMS-III

The PMS of Oklahoma Department of Transportation is characterised by the integration of a pavement performance-modelling tool with a new pavement network optimisation model for identifying and selecting cost effective projects for maintenance and rehabilitation. The unique feature of this system is the integration of a pavement performance-modelling tool and a global optimization model for pavement network analysis. Pavement performance models can be updated whenever new data are available. All models can be evaluated and alternative models can be developed using the interactive modelling tool. This system can produce satisfactory results for pavement engineers to perform pavement maintenance and rehabilitation planning for up to 20 years. Fig. 4.2 shows the structure of the Pavement Management System implemented in the Oklahoma State.

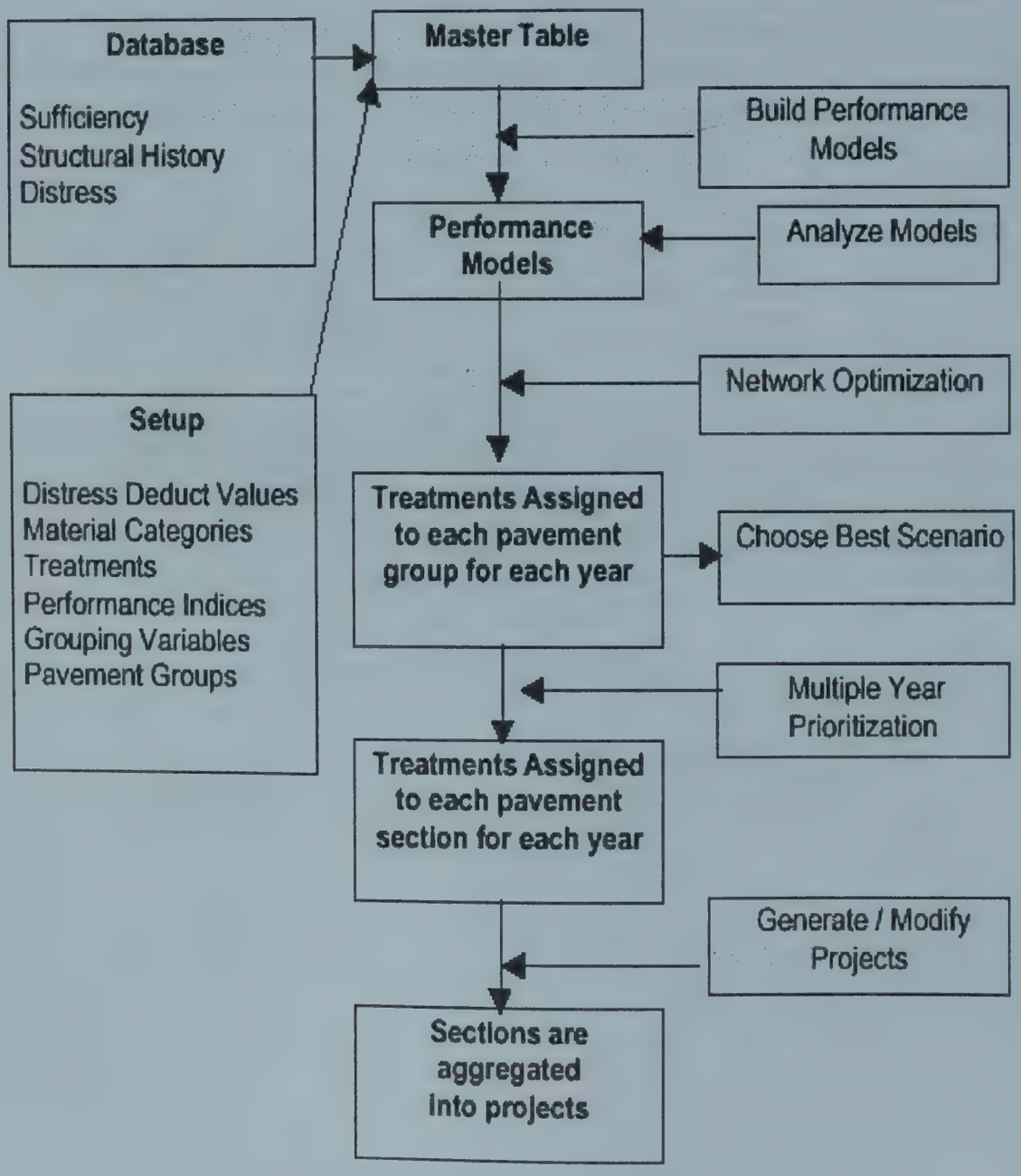


Fig. 4.2. Pavement Management System of Oklahoma State

4.1.2. United Kingdom: The "United Kingdom Pavement Management System" (UKPMS) developed by Chris Britton Consultancy has been designed to assist highway authorities in structural maintenance of pavements. It does so by improving both the systematic collection of information and the decision making process required to optimize resources and to generate a works programme and the corresponding budget. UKPMS uses innovative technology to improve treatment selection and by optimizing the allocation of funds various rehabilitation schemes. It achieves this by projecting pavement condition for all parts of the network and prioritizing schemes based on the economic return on the investment. It is suited to all types of roads and addresses the whole cycle of maintenance from identification to construction. As increasing constraints on spending and reduction in maintenance budgets combine to put pressure on maintenance management, UKPMS helps to make better use of the scant sources. Fig. 4.3 shows the flow diagram of UKPMS.

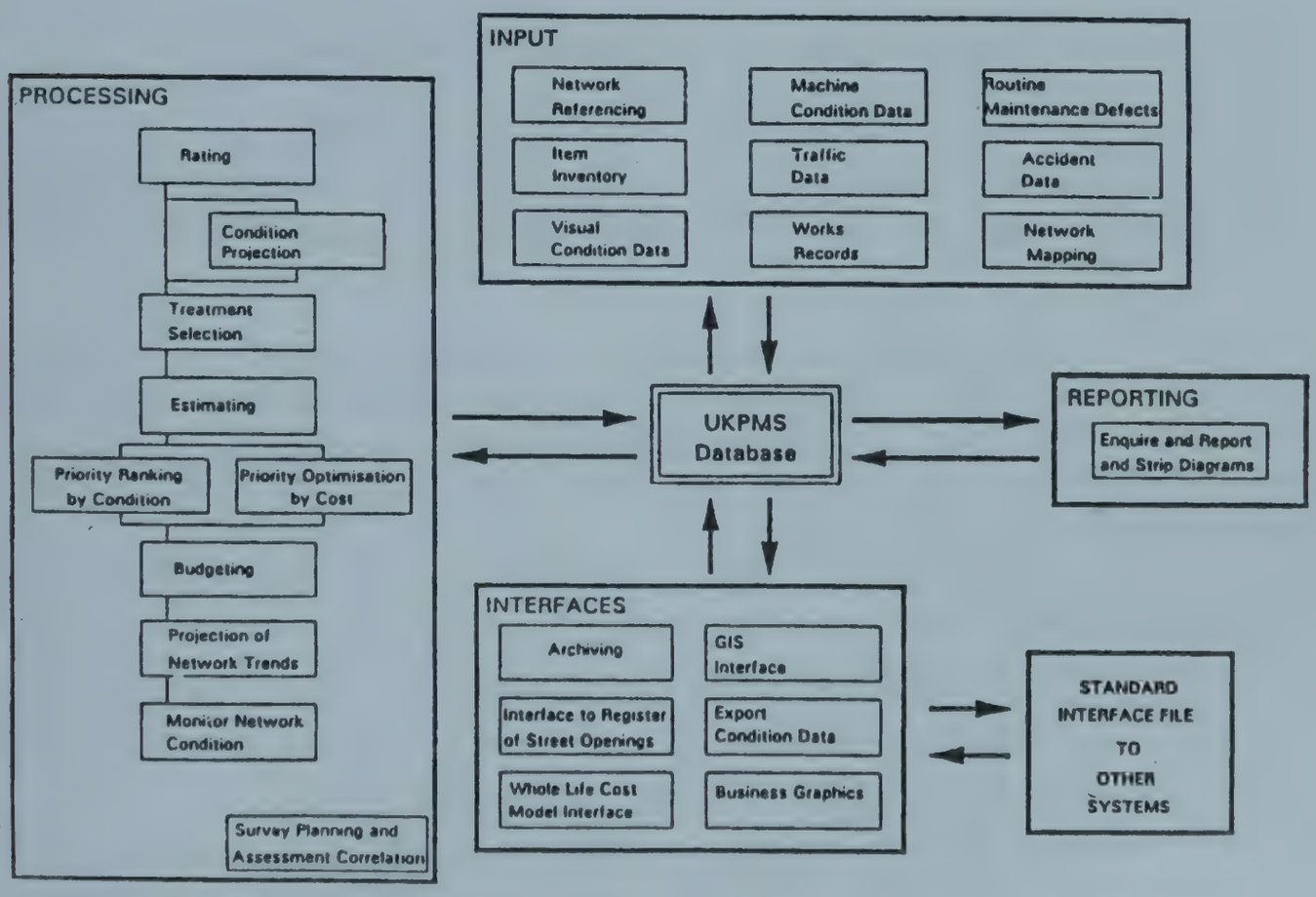


Fig. 4.3. Flow Diagram of United Kingdom Pavement Management System

4.1.3. Australia: The ARRB Transport Research Ltd. has been actively developing and promoting the adoption of PMS by road authorities to improve the efficiency of decision making and ensuring that maximum value is obtained from the funds allocated to road improvement. In Australia, there are over 12 different software packages on PMS available, which can cater for roads ranging from National Highways to low

volume rural roads. An independent assessment of these systems has been undertaken to assist practitioners in the selection of PMS package most suited to their particular situation.

The pavement condition data collection has improved considerably as a result of development of efficient and accurate equipment for data collection, including:

- Falling Weight Deflectometer (FWD) as the standard equipment for measurement of pavement deflection
- Multi-laser profilometry vehicles for recording of complete road surface shape at highway speeds
- ARRB walking profiler for the measurement of surface profile and ride quality
- Gipsi-Trac, an advanced vehicle based system for fast digital mapping of road networks, using GPS technology
- Laser based system for measurement of surface texture
- Video imaging based high-speed crack detection system
- Vehicle-based Pavement Strength Evaluator (PASE) of Victoria State Department of Transport, which is capable of assessing more than 30 km of traffic lane per day.

In another Australian PMS development for implementation of pavement management system to optimise work programmes for local government authorities a geographic information system based Pavement Management System for Salt lake city called G-PMS is utilised. The following are the benefits of GIS based PMS:

- A complete inventory of paved streets with segment number, length, width and area of the map
- Simplified storage and retrieval of existing condition information of the roads
- Updated pavement condition by crack index and recommended maintenance activities on the existing data base on the regular base
- Ability to generate a map to analyse the pavement condition of the large area
- Guaranteed integrity of various types of data for pavement management
- Justifiable budget requests to the controlling entity based on objective and factual data, and
- Long-term maintenance budget programming involving the prediction of pavement conditions while maintaining the pavement conditions at a desirable level.

4.1.4. Canada: A national legacy of pavement design and management exists in Canada, starting in 1960's by the Canadian Goods Roads Association (CGRA), continuing through 1970's and 1980's by Road Transport Association of Canada (RTAC), and currently being represented by a new Pavement Design and Management Guide of Transportation Association of Canada (TAC). These continuing efforts have all recognized that roads networks represent a major transport asset. Flexible pavements generally comprise more than 90 per cent of the total paved km. Rehabilitation and maintenance generally dominate pavement expenditures ranging from about 65 per cent to 95 per cent of the total dollars spent on the pavements. Most network level pavement management systems have been quite recently implemented, but the project level management systems have a much longer history. Figure shows the framework and major classes of activities in the Canadian Pavement Management System.

In Canadian PMS, integration of the pavement database with other road system data elements has been facilitated by the use of new referencing and relational database technology, such as, Geographic Information Systems. The wide spread method used in Canada for many years to characterize pavement serviceability has been Riding Comfort Index (RCI). Car Road Meters (bump integrator type devices) are still being used to a considerable degree, but profile-measuring devices are increasingly being adopted for roughness measurements. As well, International Roughness Index (IRI) is being used by several agencies in Canada, either directly or to estimate RCI, such as, in British Columbia:

$$RCI = 10 \times e^{-0.18IRI}$$

The primary methods of structural evaluation in Canada are deflection base; e.g. Benkelman Beam, Dynaflect and Falling Weight Deflectometer, with the latter becoming the primary device of choice and the former now seeing only very limited use. The indices commonly used are Riding Comfort Index (RCI), Structural Adequacy Index (SAI), Surface Distress Index (SDI), a composite measure Pavement Quality Index (PQI) and Pavement Condition Index (PCI). Performance prediction models commonly are for RCI, PQI or PCI *vs* pavement age, and are mainly developed through regression, Markov and Bayesian techniques.

Current network level needs are identified by most agencies on the basis of minimum levels of acceptability and engineering judgment; some have performance prediction models to identify future needs. The most common rehabilitation treatments for these needs are milling, recycling and overlaying. Most of the agencies select M&R treatments based on life-cycle economic evaluation, and some include user costs also.

Fig. 4.4 shows the Framework of Canadian Pavement Management System.

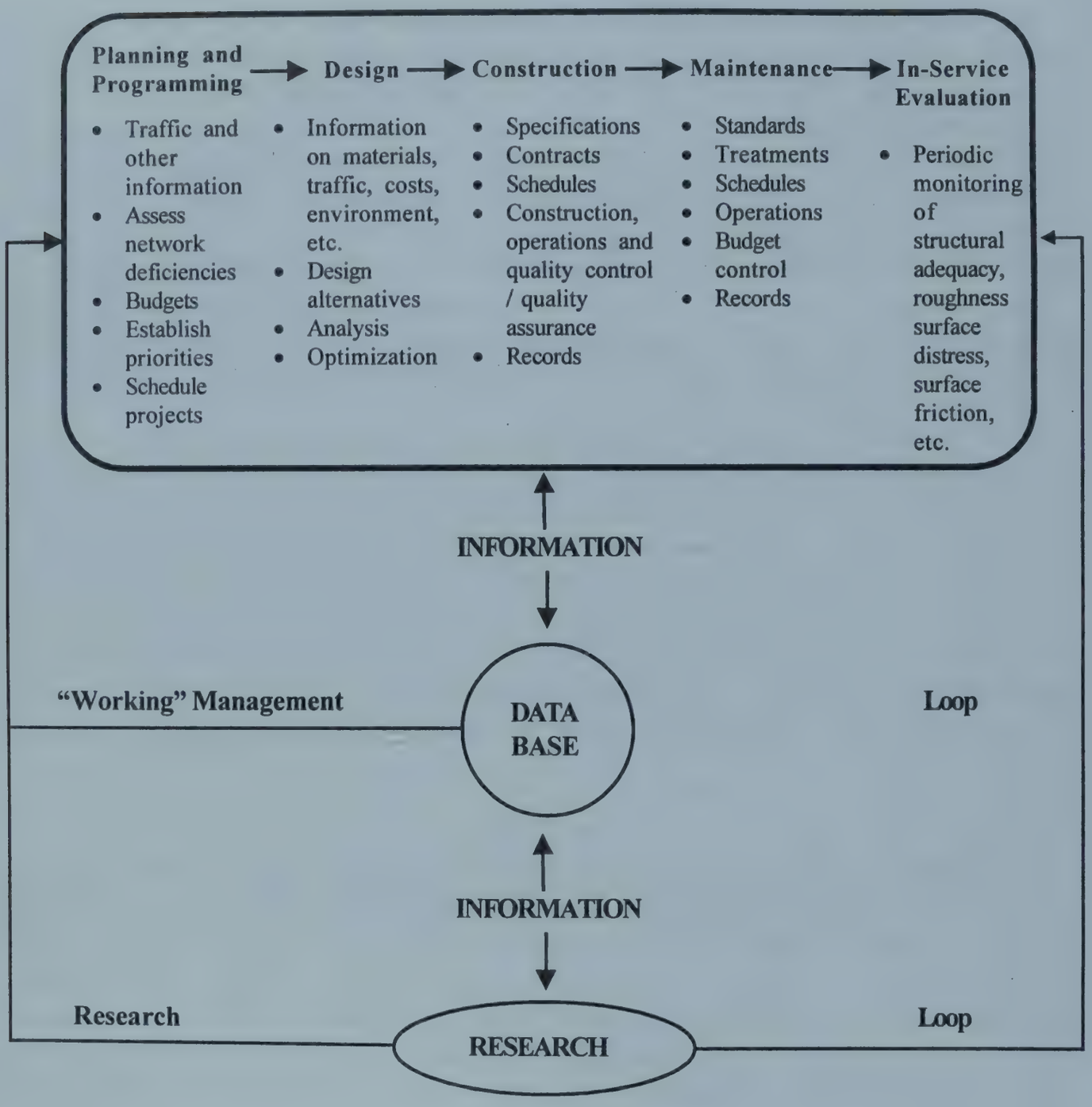


Fig. 4.4. Framework of Canadian Pavement Management System

4.1.5. Denmark: The Technical University of Denmark in cooperation with Dynatest Engineering developed the Dynatest Pavement Maintenance and Rehabilitation Management System, DPMS for short. This system is capable of predicting future pavement condition for a number of years on project as well as network level. It contains an optimization procedure to determine that combination of M&R measures that will ensure the optimal use of the budget. The system is not only based upon objectively measured functional and structural pavement characteristics, but it also ensures that the knowledge and experience of the local engineer is incorporated. The system ensures compatibility in all the steps of data flow, right from the collection of data out on the road to the final consequence analysis. DPMS is schematically illustrated in Fig. 4.5.

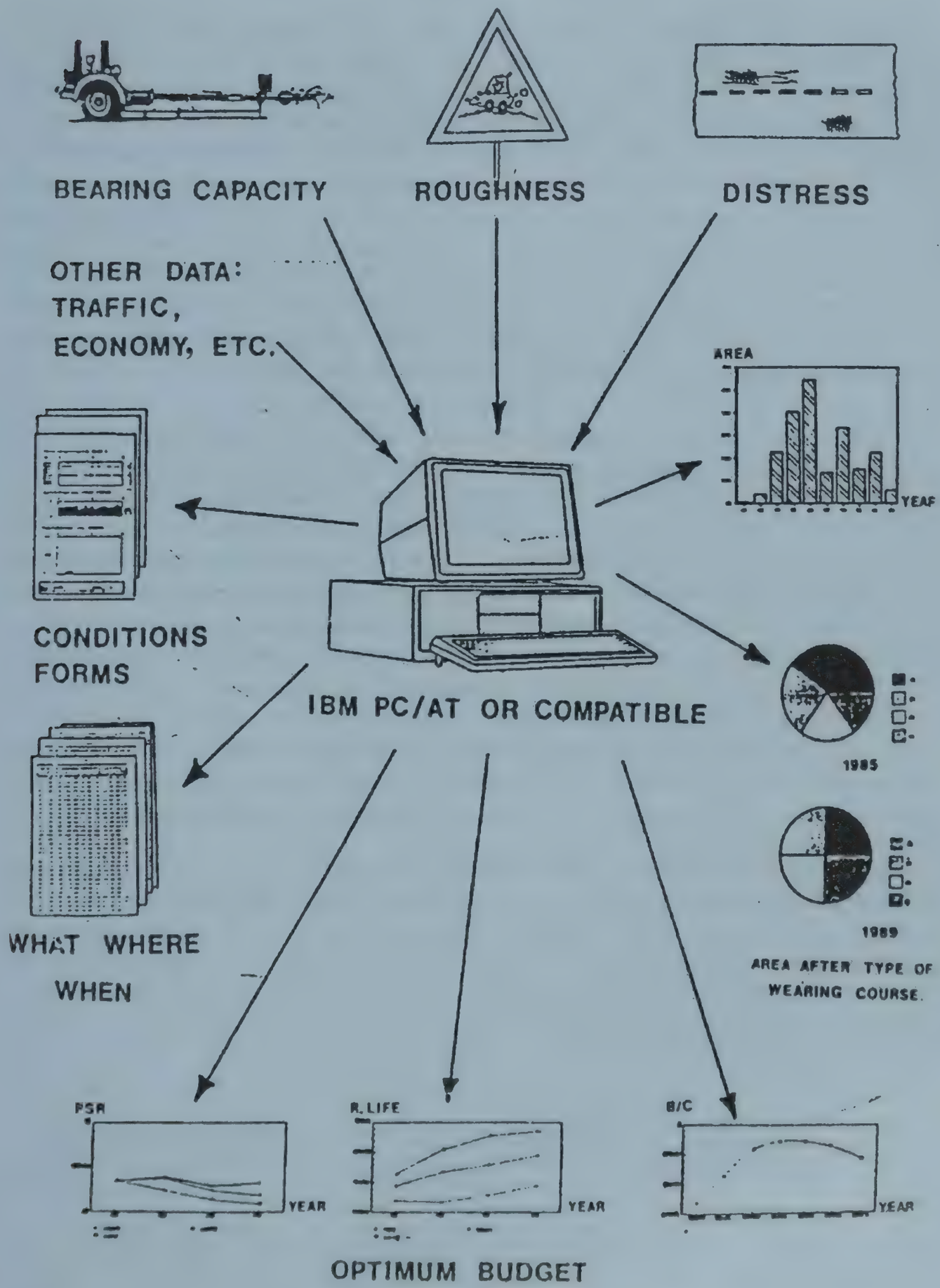


Fig. 4.5. DYNATEST Pavement Management System

4.1.6. New Zealand: It was only in late 1998 that the Government of New Zealand decided to implement a National PMS. The initial objective was to have a completed preliminary system in place and integrated with the existing National Road Asset Management Program (RAMM). This consisted of a basic inventory and pavement condition database along with an algorithm for selecting maintenance treatments. The new PMS has been built on the existing road management inventory system and the existing funding framework. The software package dTIMS (Deighton Total Infrastructure Management System) along with a hybrid set of predictive models from HDM-III and HDM-4 has been adopted for the development of PMS. This PMS would be used by over 70 different road-controlling authorities (city, district and state level) responsible for a network of more than 1,00,000 km of sealed and unsealed roads. Consultants engaged in management of the road networks would also use it.

4.1.7. France: The French Directorate of Road in association with LCPC (Central Public Works Laboratory) and the SETRA (Roads and Motorways Engineering Department) has developed a road management system, based on two complimentary suites of tools: the VISAGE road database with its own facilities for the graphic representation of data and the GIRR package with its various data analysis modules. This system was implemented in 1992 by the state departments on the National Roads Network and extended more widely in 1996 to regional networks also. The VISAGE and GIRR software packages use a rational approach for the management of pavement maintenance. It is an approach designed around four main stages: after an inventory on the nature of the road network, and an assessment of its condition, a maintenance policy must be defined and then applied through works programming. Finally, network follow-up is carried out on a regular basis to measure the effects of the policy put in place and, when applicable, to adopt the appropriate corrective actions.

The distribution of the GIRR software package to the road authorities started in 1996. At the beginning of the year 2000, this system was being used by 52 per cent of the field departments of the Road Directorate, 21 per cent of the departmental road network managers and 5 urban road network managers. Though, none of these departments put this system to systematic and extensive use, but progress is being made. Flow of activities in the French PMS is explained in Fig. 4.6.

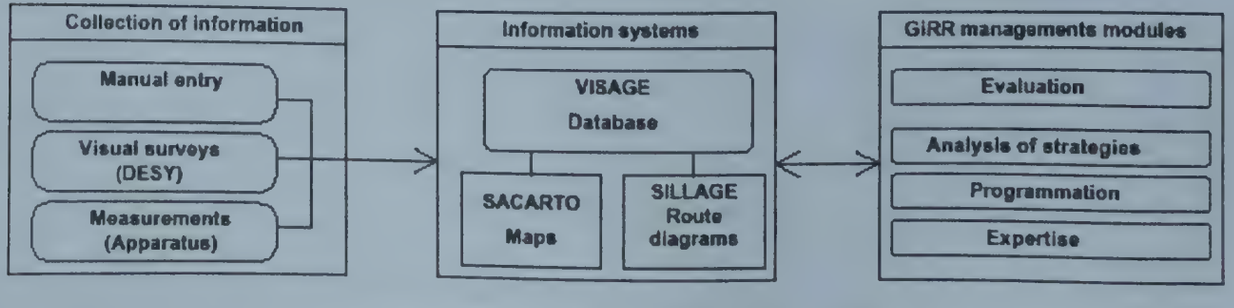


Fig. 4.6. Structure of VISAGE and GIRR

4.1.8. Sweden: The Swedish PMS has been developed and implemented at several levels, i.e., Strategic level, Programming level and Project level. The main objective of PMS at strategic level is to produce objective information as decision support in fund raising, in allocation of available budgets to the regions. The objective of PMS at programming level is to serve as a tool to identify candidate projects and the objective of the PMS at project level is to assist in planning and design of individual projects.

The Swedish National Road Administration (SNRA) also studied the possibilities of using the Finnish pavement management system HIPS (Highway Investment Planning System). By using this system, analysis of the whole Swedish State road network has been conducted on a yearly basis since 1996. But, it has now been decided to make use of Norwegian Pavement Management System as a stand-alone planning module w.e.f. spring 2001.

4.1.9. Norway: The Norwegian Public Road Administration (NPRA) has implemented a new Pavement Management System called PMS99. 19 regional road administrations as well as the Central Road Directorate use this programme. This Windows based version of PMS has replaced the earlier DOS based version, which could not make use of the data stored in the Road Data Bank to its full potential. PMS99 is used primarily by regional pavement engineers to plan pavement maintenance works at the project level for a period of 6 years. PMS99 uses simple prediction models based on historically measured data for each road section. This helps the engineers to make right decisions concerning the location, timing and extent of future pavement works within their regions. Fig. 4.7 shows the main structure of PMS99.

4.1.10. West Germany: A road preservation management programme called UMASTER has been developed with the objective of computations of the cost to the agencies responsible for financing road construction and preservation. But the road preservation programme includes only those types of conditions, which are relevant to medium and long range planning, and not those which require immediate attention, e.g., filling of potholes. Funding needs are computed based on periodically performed surveys of roadway conditions and related predictions of the behaviour of the future course of development of the condition of highways. Methods have been developed for forecasting the behaviour of flexible pavements taking into account their conditions of use and climatic influences. Quantitative forecasting models for the aspect of road conditions described as rut depth, water retention and network of cracks are in the process of development.

4.1.11. Italy: Pavement Management Systems have been commonly used for yearly maintenance and rehabilitation planning of the Italian roads since 1988. As Italy's road network is very complex, it requires a computerized system for the development of pavement maintenance programme. High performance equipments are

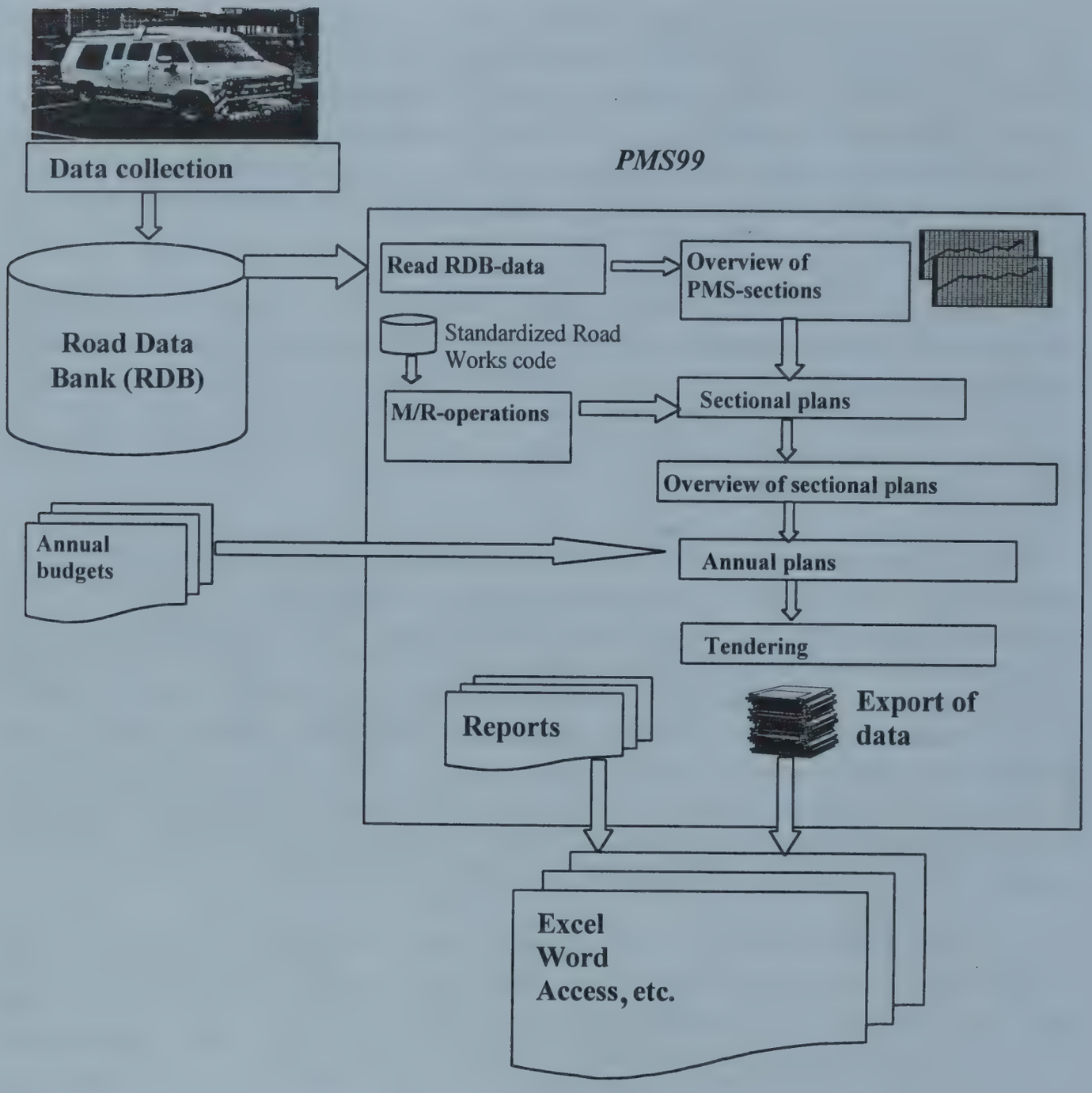


Fig. 4.7. The Main Structure of PMS99

used to measure the physical parameters of pavements and accordingly, improvements in the optimization of maintenance and rehabilitation strategies are carried out. An automated decision making algorithm outlines multi-year maintenance plans, hence ensuring that the various actions to be taken are fine tuned with their effectiveness over time and the financial resources available. The fact that the road network is subjected to continuous surveillance makes it possible to maintain high levels of maintenance service in line with the requirements of the users.

4.1.12. Austria: Increased road deterioration in Austria combined with the demand for a fair distribution of the available budgets urged the Australian Federal Road Administration to take necessary steps for the implementation of a nationwide PMS. A number of extensive studies by different investigators and improvements in administration ultimately paved the way for the start of very first application in practice of the Austrian Pavement Management System VIAPMS-AUSTRIA in late 1999. The Institute for Road Construction and Maintenance and Vienna University of Technology provided the road specific data and the practical use of VIAPMS analytical software. This PMS is the only available tool in Austria that underlined the necessity of allocating budget resources for pavement maintenance. Fig. 4.8 shows the structure of the database module of the VIAPMS.

THE STRUCTURE OF THE AUSTRIAN ROAD DATA BASE

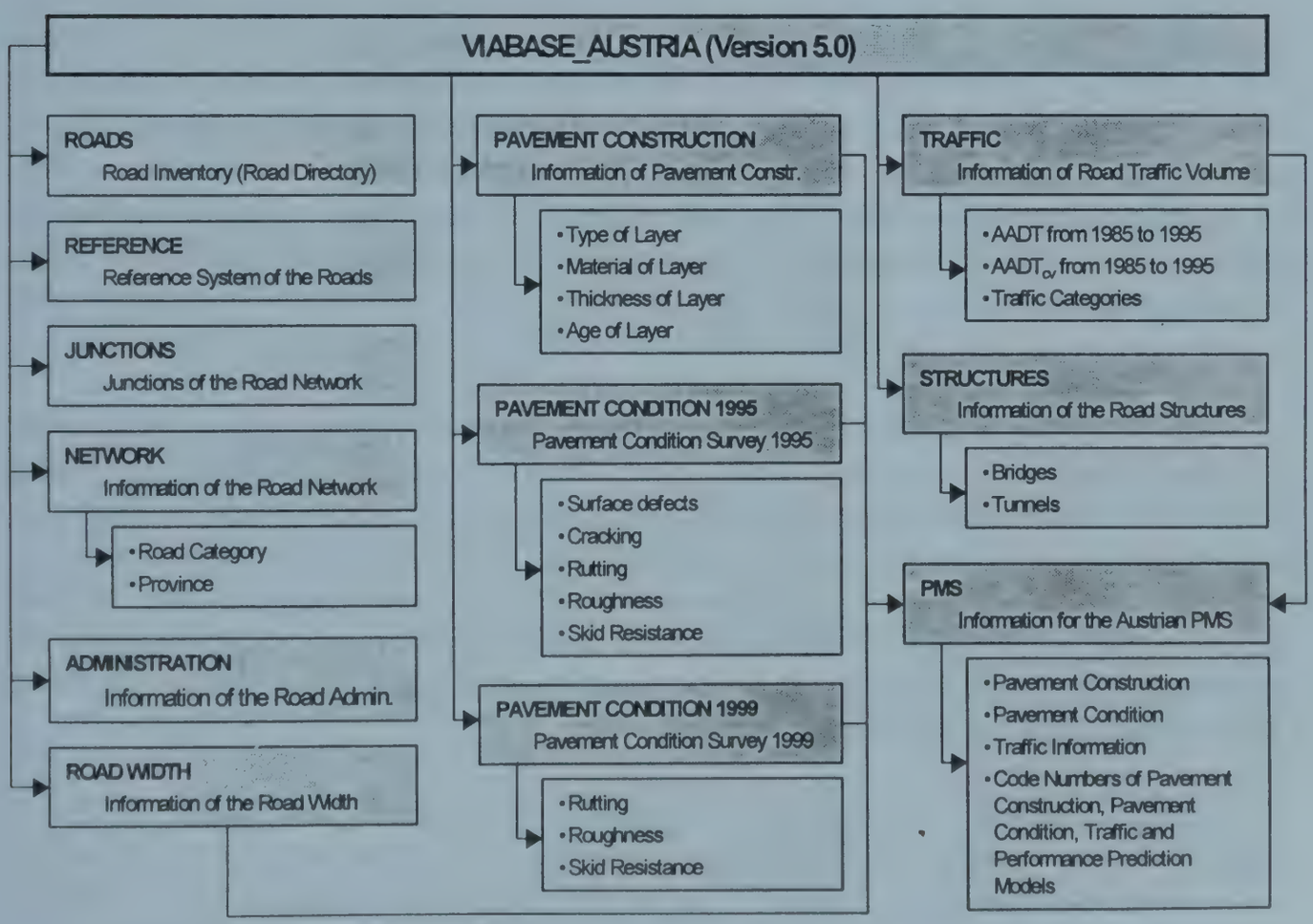


Fig. 4.8. The Structure of the Austrian Road Database VIAPMS

4.1.13. Belgium: The Belgian Road Research Centre has developed two different pavement management systems; SOGER and GERSEC for Belgian State highways and low volume roads respectively. An automated data capture system SASER collects the information about the state of road and forms a substantial part of the Belgian Road Database.

The State of Flanders has developed a new maintenance planning system for pavements. This system uses longitudinal evenness, rut depth, skid resistance and bearing capacity as road qualities. But the collection of data of the road qualities is rather expensive because of use of high-tech equipment and skilled people to run them. The longitudinal evenness is measured with the French APL, Rutting with an ultrasonic device developed at Queens University of Belfast, deflection with FWD and skid resistance with a laser texture meter SCRIMTEX, which is a modified version of the SCRIM developed by TRRL. Different prediction models are given alongwith all the individual intervention threshold values. The damage factor is derived from the visual inspection. The overlay design is based on the deflection measurement. A statistical approach is also provided in the system for the distribution of maintenance budget between the different provinces and the different road networks.

4.1.14. South Africa: The Roads Branch of the Transvaal Provincial Administration (TPA) administers the planning, construction and maintenance of 44,000 km, of roads in the Transvaal Province of South Africa. These roads include roughly 200 km, of freeway, 20,000 km, of black top roads; the remaining roads having a gravel wearing course. A pavement management system for the surfaced roads was initiated in 1982 and fully implemented in 1985. The system has gradually been refined over the last decade while the funds for road maintenance and rehabilitation have dwindled. More recently, funds have been reduced significantly and the adoption of the most cost-effective rehabilitation strategy has become a primary goal of the system.

The PMS implemented in the Province of Western Cape consists of an input parameter module, project identification and ranking module incorporating reseal, maintenance and rehabilitation models, and an economic analysis and optimisation module incorporating performance prediction model. The process of project identification and prioritization is based on a rational methodology, which enables the highway agency to plan maintenance and rehabilitation activities and manage the road network cost effectively. Fig. 4.9 shows the maintenance management framework of the South Africa Department of Transportation (SADOT).

4.1.15. Chile: In mid eighties, the highway authorities of the Ministry of Public Works of Chile started a five-year project for the implementation of a Pavement Maintenance Management System. The objective of the project was to establish maintenance policies at road and network levels. Two major Universities of the country, University of Chile and University of Pontificia were entrusted with the task of developing the separate systems for rigid pavements and flexible pavements respectively. The Pavement Maintenance Management System for flexible systems, called GIMP system provides information to the decision makers about what, when and how to do the optimum maintenance on a pavement section in order to maximize the available resources. The inputs of the System include construction data, periodic monitoring, traffic data, climatic data, maintenance and costs. The outputs of the system include

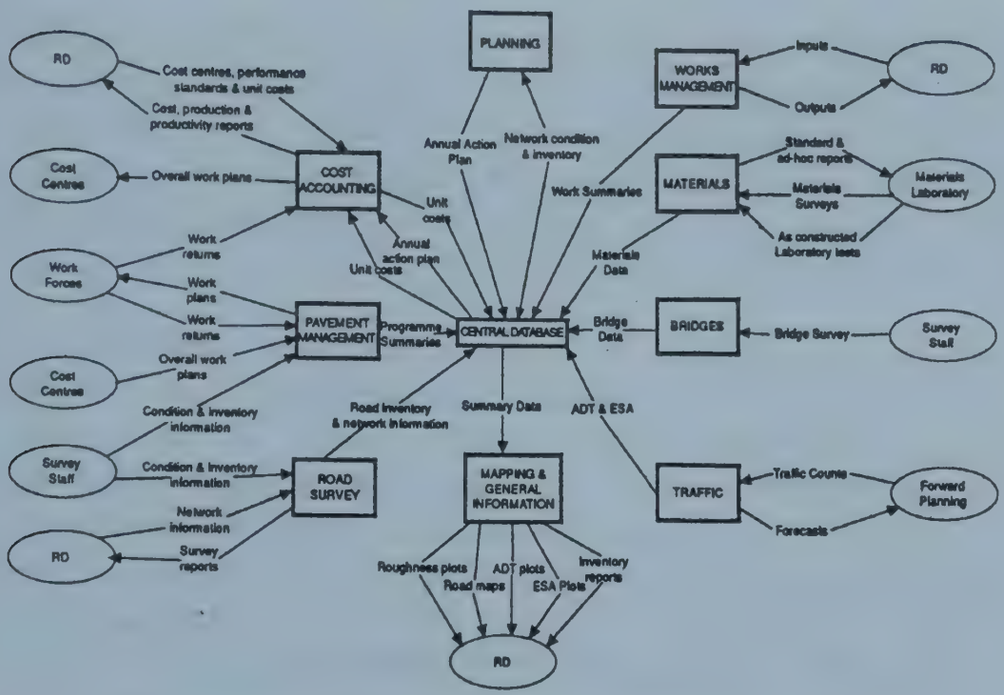


Fig. 4.9. Maintenance Management Framework of SADOT

technical evaluation of the present pavement condition, prediction of the future behaviour of the pavement and economical evaluation. Fig. 4.10 gives a schematic presentation of GIMP.

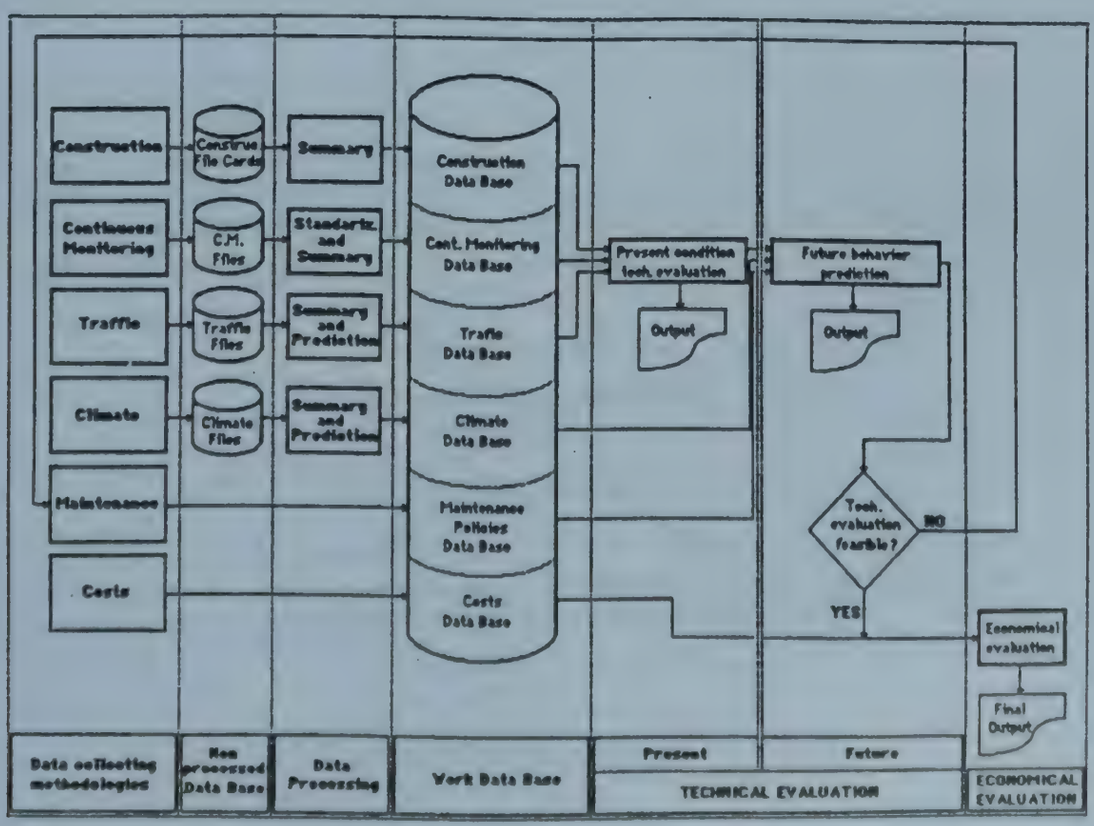


Fig. 4.10. The GIMP System

4.1.16. China: Pavement management system in China has rapidly progressed from a concept to a broadly accepted practice over the past few years. A methodology has been established for the implementation of PMS to the actual road network of Southeast Economic Developing Region of Qinghai, where a large amount of new construction will be undertaken, while rehabilitation and maintenance of the existing pavements will be carried out at the same time.

The effectiveness and major functions of applying a PMS in an actual road network depend not only on its structural components, but also on the organisation of the particular agency within which it is implemented. In case of Qinghai PMS, it was considered important that the pavement management include the following essential components. The existing road network database, presents investment policy and new construction plans, pavement performance evaluation and prediction, cost effectiveness and need analysis, rehabilitation alternative strategy analysis, priority ranking and maintenance programme. Qinghai PMS is illustrated in Fig. 4.11.

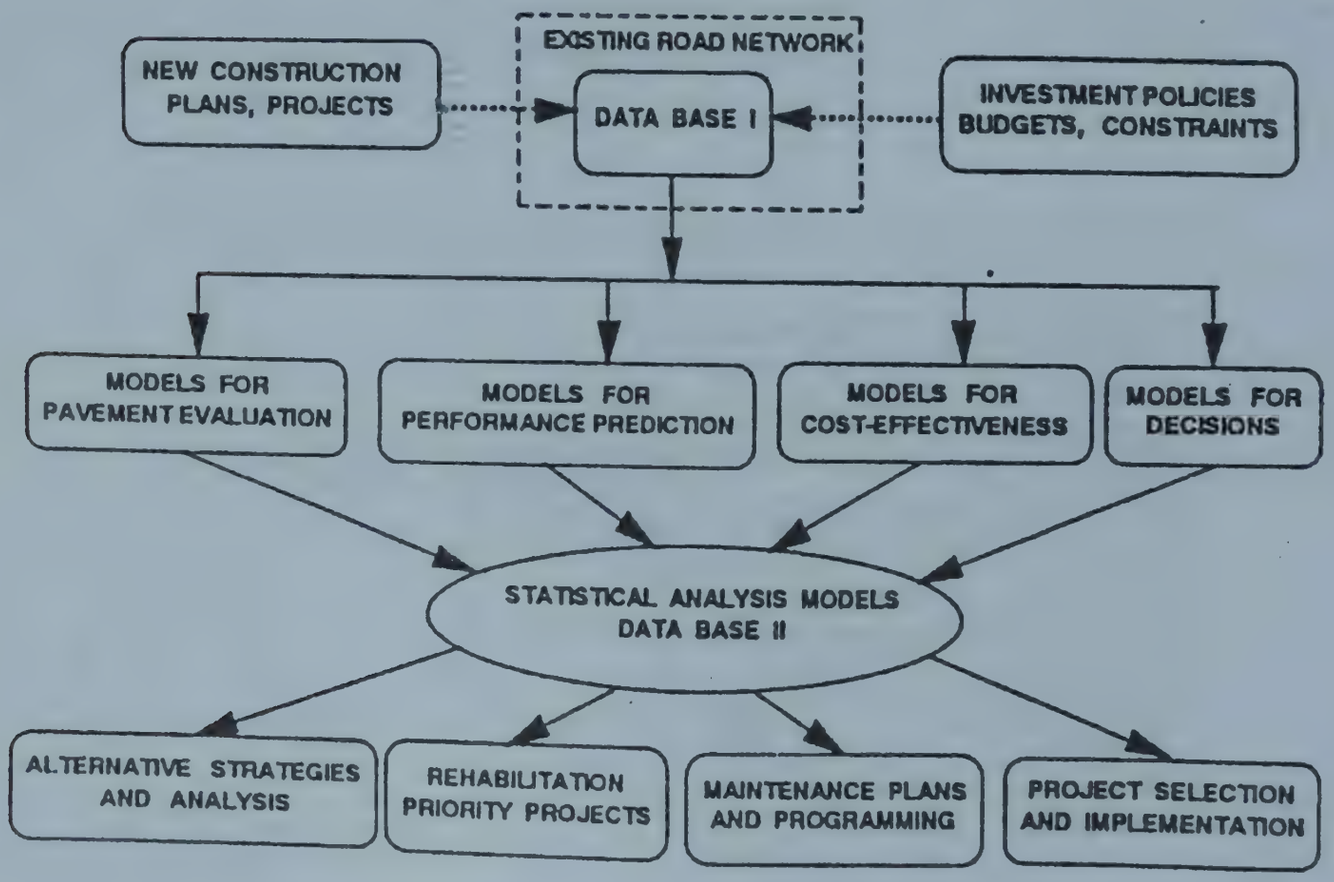


Fig. 4.11. Flow Diagram of Qinghai PMS

4.1.17. Japan: The Ministry of Construction in cooperation with Japan Public Highway Corporation and Tokyo Metropolitan Bureau have developed and implemented a PMS for Japanese roads. The PMS was initially implemented to support pavement design and construction with data stored in a central database, in order to rationalize MR & R activities. But this system is presently used as pavements inventory and not as a decision support system anymore, because of incompatibility with current computer systems and lack of economic efficiency criteria. But still, this system provides a valuable repository of data. Fig. 4.12 shows a flow chart of activities involved in Japanese PMS.

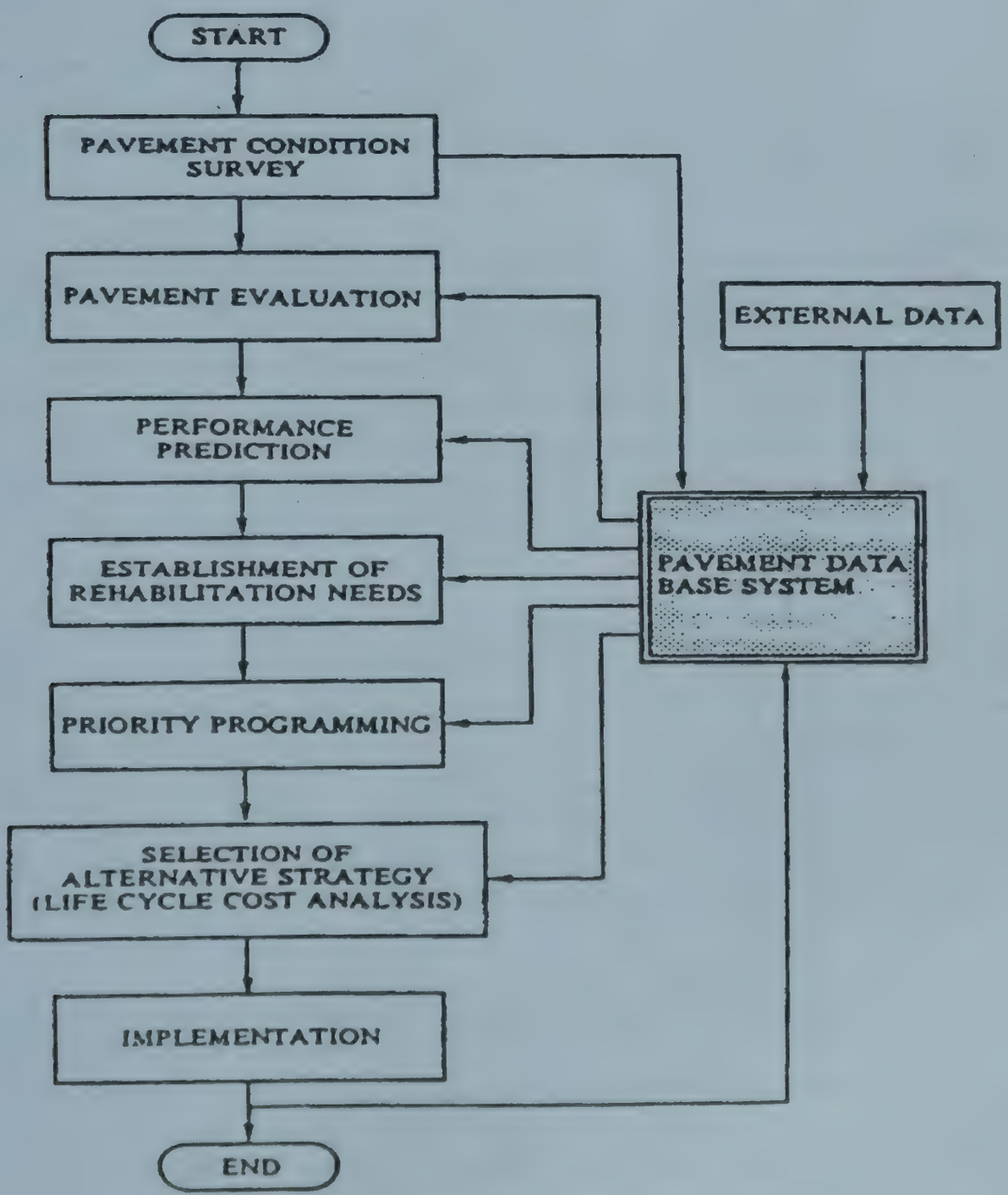


Fig. 4.12. Flow Chart of activities involved in Japanese PMS

A GIS based Highway Pavement Management System (HPMS) has been developed to examine the performance and repair needs of the road network of a selected study region in Japan by assuming different budget levels and maintenance policies. In this system, the GIS application provides a flexible tool for interactive analysis of policy trade-off, clear display of results, and coordination between related activities. Also, it improves data availability by spatially relating relevant information and facilitating data exchange between different administrative offices.

4.1.18. Philippines: The Government of the Republic of Philippines has embarked on an initiative to introduce formal PMS practices into the maintenance management of the national road network. The system consists of an accurate and up-to-date locational reference system for the road network, automated pavement condition data collection technique, data management and data presentation techniques based on an easy to use Geographic Information System (GIS) and a pavement investment analysis system based on World Bank's Highway Design and Maintenance Standards (HDM III) package.

4.1.19. Korea: The Bureau of Public Roads (BPR) of the Republic of Korea has established a Road Maintenance Management System with the assistance of a Consortium made up of Korean and French Consultants. The development of RMMS has made it possible to conduct a survey of the network, to acquire information about its condition, to determine maintenance needs as a function of traffic, to establish a budget for a period of ten years combined with a maintenance strategy, and finally to keep track of the condition of the road network at all times, with the particular purpose of assessing the effectiveness of the maintenance strategy chosen and correcting the model if necessary.

4.1.20. HDM developments: The Highway Design and Maintenance Standards Model (HDM-III), developed by the World Bank, has been used for over two decades to combine technical and economic appraisals of road projects, to prepare road investment programmes and to analyse road network strategies. The International Study on Highway Development and Management (ISOHDM) has been carried out to extend the scope of the HDM-III model, and to provide a harmonised systems approach to road management, with adaptable and user-friendly software tools. This study has resulted in development of the Highway Development and Management Tool (HDM-4).

The scope of the tool has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. Emphasis was placed on collating and applying existing knowledge, rather than undertaking extensive new empirical studies, although some limited data collection was undertaken. Wherever possible, creative new approaches were developed for applying up-to-date knowledge to the technical problems and management needs of different countries. The overall structure of HDM-4 is illustrated in Fig. 4.13.

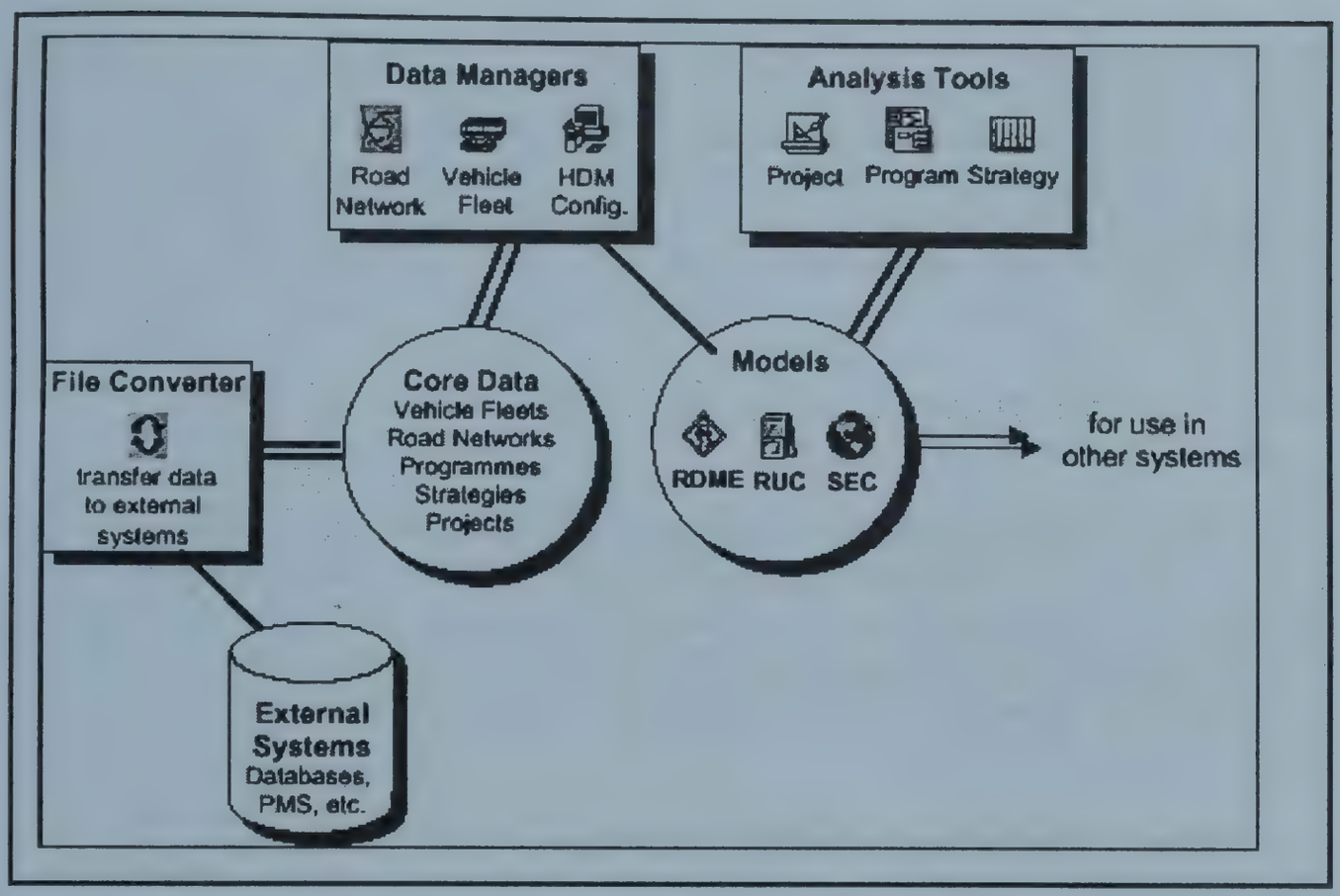


Fig. 4.13. Structure of HDM-4

The HDM-4 system is designed with a modular structure, thereby permitting its total or selected integration with Pavement Management Systems. Any of the three application modules can be incorporated within a PMS. In addition, the technical relationships built into HDM-4 are contained within Window libraries, which can be linked into existing PMS so that a common set of pavement deterioration and road user cost models can be incorporated in other PMS.

4.1.21. Hungary: A pavement management system for urban road network was developed in Hungary. The network-level tasks are solved on the basis of Markov transition probability matrices. The project-level part relies on heuristic technique. The candidate sections are ranked using their cost/benefit ratios. The yearly discounted cost of routine maintenance, the discounted vehicle operating costs and the discounted cost of the optimum intervention are considered. The optimum intervention depended on the initial combination of condition, the pavement type and the traffic amount.

4.1.22. Burlington: The Burlington Road Infrastructure Management System is used to make effective use of PMS in the city roads to determine the present status of the road network, predict performance, and determine an optimum long term rehabilitated programme. The system assesses the condition of each road, predict

the year in which each road section will fall below a minimum pavement quality index and recommends when cost effective rehabilitation should optimally occur. The road asset capitalization model uses the pavement quality index as the proportionate percentage of the remaining asset value and it takes into consideration performance prediction curves as well as the life-cycle of a road. The city has also developed methods for determining local street reconstruction priorities. Burlington has succeeded in introducing its PMS and integrating it into a cost-effective budgetting process. In view of this integrated approach to road infrastructure management, the city's programme is viewed as a highly effective, proactive one that will assist the municipality in avoiding a road infrastructure crisis.

4.1.23. Thailand: Effective maintenance strategies for municipalities in Thailand were developed. The PMS has improved the effectiveness of planning by ascertaining the budget required to bring the network upto a superior standard, tailor the programme to allow best use of available budget, ascertain the effect of different intervention levels on maintenance spending and reallocate funds to provide an overall improvement in network condition.

4.1.24. Study conducted at California: The California Department of Transportation (Caltrans) has developed a PMS that is designed to assist management in making cost effective decisions regarding pavement maintenance and rehabilitation. Caltrans has given rating system for flexible pavements. The flexible pavement condition rating includes alligator and block cracking, longitudinal cracking, transverse cracking, ravelling, rutting and patching. The caltrans system brings together the following system approach:

i) Taking inventory of pavement condition
ii) Analysing extent and severity of pavement condition
iii) Identifying appropriate repair strategies
iv) Identifying cost effective strategies and reasonable alternatives for candidate projects
v) Relating the repair strategies to the appropriate caltrans highway programme structure

The flexible pavement condition evaluation procedure used in selecting the dominant strategy is illustrated in Fig. 4.14 and travelled way evaluation process for selecting a strategy is shown in Fig. 4.15.

4.1.25. Study conducted at Utah: The Utah Department of Transportation (DOT) faced with a serious shortage of funds for rehabilitating failed pavements. It was decided to find out at what level-of-service, the pavement maintenance would be the most economical maintenance for the State and for users. Cost curves and cost estimates were prepared for upgrading pavements to an acceptable level from

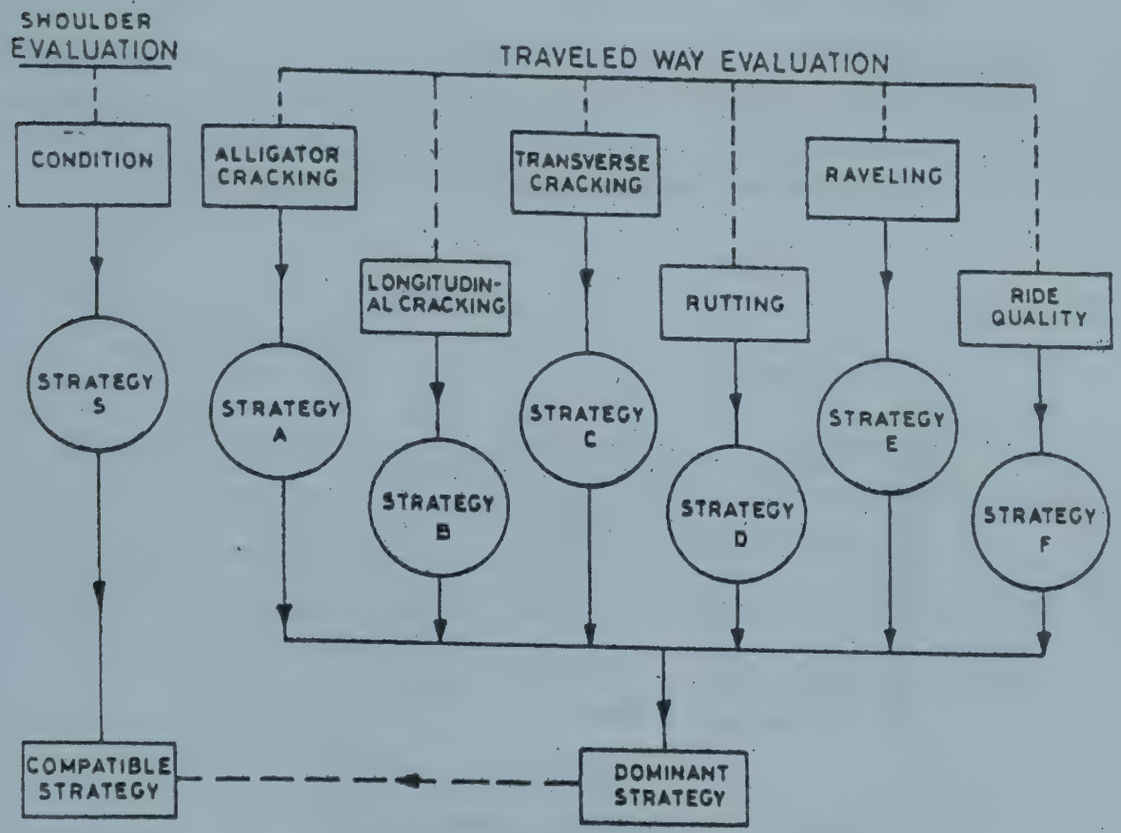


Fig. 4.14. Caltrans Flexible Pavemnt Condition Evaluation Procedure

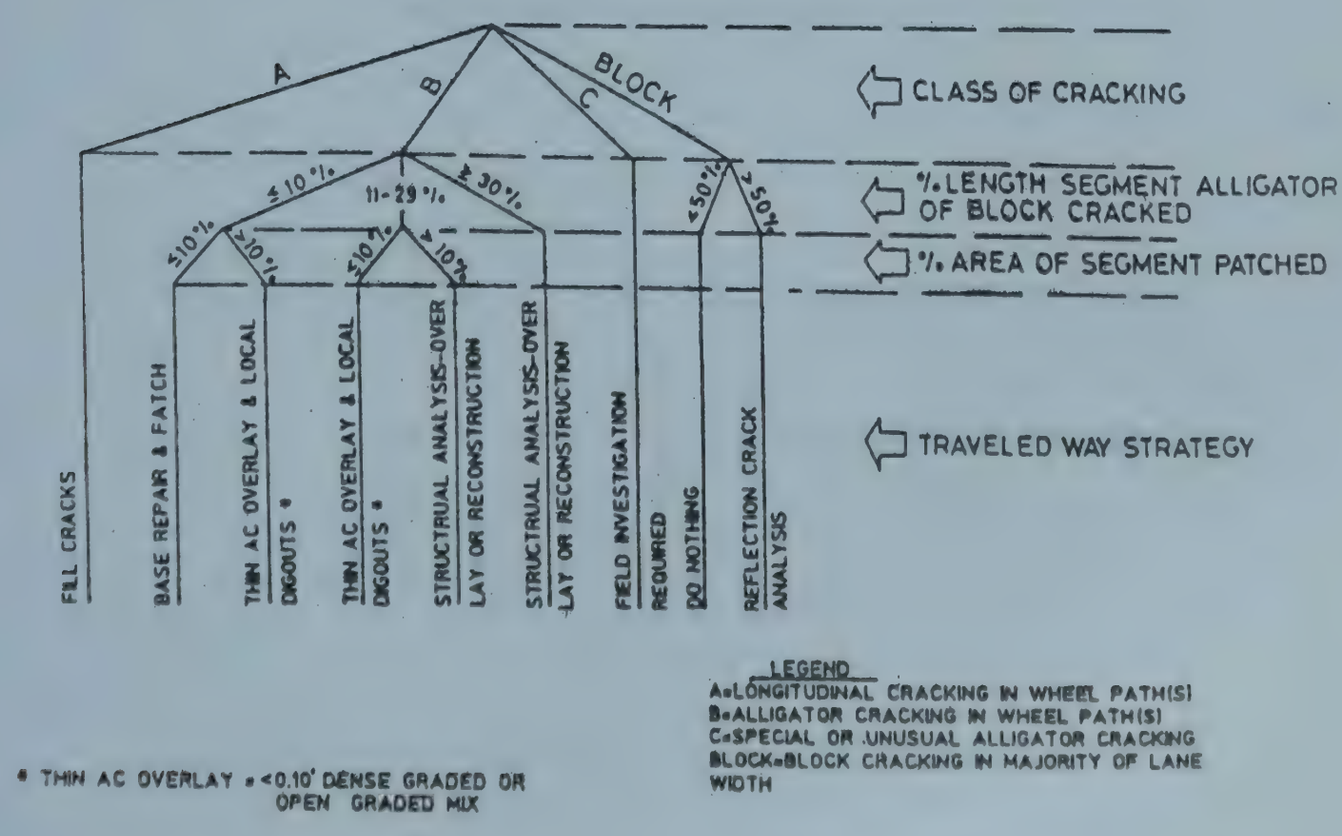


Fig. 4.15. Cltrans Flexible Pavement Alligator Cracking Rehabilitation Decision Tree

various present conditions. Fig. 4.16 shows the overlay thickness required to bring a pavement to an acceptable level of performance from its present condition. User costs, maintenance costs, and rehabilitation costs were included in the analysis. These costs varied with the condition of the pavement. Four different strategies were analysed to determine relative costs and benefits as shown in Fig. 4.17.

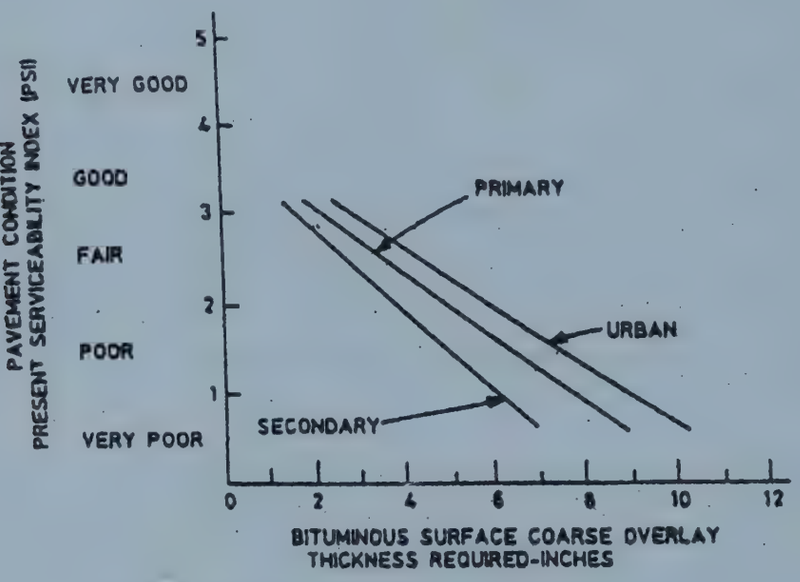


Fig. 4.16. Utah-Required Overlay Thickness Based on Pavement Condition-20 Years Design

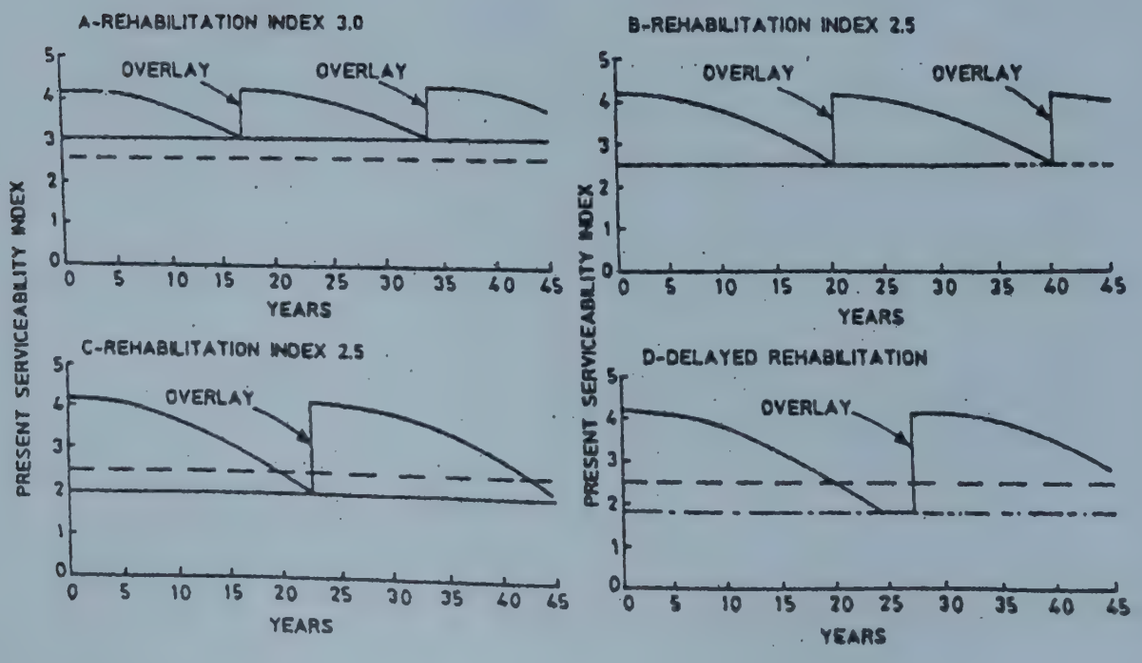


Fig. 4.17. Utah's Pavement Rehabilitation Design Strategies

The details of the strategies are :

I) **Strategy A** : It requires that each pavement be rehabilitated when its PSI drops to 3.0. This means that for a 20 year be rehabilitated when its PSI decreases to 2.5, requiring an overlay on design period, each pavement will be overlaid on the average of once every 17 years rather than once for every 20 years.

II) **Strategy B** : It requires that each pavement be rehabilitated when its PSI decreases to 2.5, requiring an overlay on the the average of once every 20 years, PSI value 2.5 is the design level for higher volume roads.

III) **Strategy C** : It requires that each pavement be rehabilitated PSI of 2.0. It would be overlaid approximately once every 23 years for a 20 year design period.

IV) **Strategy D** : It represents the present status level of effort required to maintain it. Each pavement could be overlaid once every 27 years. As pavement deterioration reached to a poor level of performance, additional maintenance is required to maintain pavement integrity.

4.1.26. Road transport investment model: Attempts have been made to develop scientific tools in the form of inter-related mathematical models, featuring mainly performance indicators, to help in planning a rational maintenance strategy or to formulate maintenance management. One such effort was made by TRRL (UK) based on the Kenya Study and is called "Road Transport Investment Model" (RTIM). Cracking model, wherein cracking and patching were considered together, and a roughness progression model were developed. The limitations include the sections considered for developing these models, which were mostly with cement stabilised base and narrow range of pavement strength.

4.2. Appraisal of Work Done in India

The concept of PMS was realized in our country only in the mid eighties. Since then, a number of important studies of direct or indirect interest to Pavement Management System have been planned and conducted in India. The maintenance and management of pavements have been receiving considerable attention during the recent past. A number of studies have been taken up in the last decade, aiming towards the rationalization of road investment policies and better road management. Of late, PMS in India has got some impetus and efforts are now on to develop Computerized Pavement Management Systems for various categories of roads. A brief description of some of these important studies is presented here.

4.2.1. Maintenance management studies on rural highways: Pavement performance data from in-service pavements on National and State Highways collected over ten years in the southern Indian States has been used by Bangalore University in developing pavement deterioration models under this study. The models have been

validated and have been applied to predict the remaining service life of existing highway pavements based on different pavement performance indicators. The basic tasks in the development of performance models are the prediction of structural and functional deterioration of the pavements. The variable quantifying the initial structural condition of the pavement, i.e., initial deflection has been considered as the strength parameter in the models. Crack width which indicates severity of distress level has been considered in the development of crack area models. These models can be represented in terms of the increase in rebound deflection alongwith the development of cracking and rutting. Functional deterioration is found to depend on thickness of layers, structural adequacy, initial unevenness, axle load repetitions and age of pavements.

The models are simple and can be used to estimate the structural as well as functional behaviour of flexible pavements after anticipated traffic loading and to find the allowable traffic loading at different limiting values of deflection, rut depth, crack area, PSR and unevenness index. Computer programmes have been developed to select the best strategy after considering life cycle cost and design life for use of practicing engineers.

4.2.2. Development of maintenance management strategy for highway system: The study was undertaken at University of Roorkee. The objectives of the project were to identify the deficiencies in maintenance practices, causes of failures and treatment to develop an approach for maintenance management strategy for highway system. From the study results, it is found that the test sections considered in the present study have crossed their maximum acceptable limits of deflection. Strengthening measures, i.e., overlays were suggested to increase the structural capacity. The overlays were designed based on the cumulative number of standard axles rather than the total number of commercial vehicles. The overlay requirements have been worked out and recommended that the corrective measures be provided on the existing surface before strengthening. Investment needs for M&R works of different sections have been estimated based on the requirements of corrective and strengthening measures. Investment strategy for priority fixation amongst the study sections for maintenance and rehabilitation requirements was developed with a view to take rational decision.

4.2.3. Input studies for development of PMS

i) Road User Cost Study (RUCS)

A comprehensive Road User Cost Study (RUCS) was completed in India in 1983. This study was jointly sponsored by the Government of India and the World Bank; and was implemented by the Central Road Research Institute (CRRI), New Delhi. In this study, relationships have been developed between components of vehicle operation costs (VOC) and their governing factors under typical roadway, traffic and environmental conditions in India. In Updated Road User Cost Study (URUCS) in 1991,

equations were developed for predicting each of the components of VOC for the new generation of vehicles, like, fuel-efficient cars, light commercial vehicles and multi axle vehicles, etc. The RUCS is in the process of being updated once again to take into account the present day traffic scenario.

ii) Pavement Performance Study (PPS)

This study was sponsored at the CRRI (1992) by the Ministry of Surface Transport (MOST) as a sequel to RUCS with a view to develop data for total transportation cost model for Indian conditions. The main objective of this study was to develop pavement performance data for the pavement materials normally used in the country. During this study, pavement degradation models over a period of 5-6 years have been developed for in service pavement sections. This study has been further extended to specially designed and constructed pavement sections on in-service highways for more accurate data generation and refinement of models developed under existing pavement sections.

The most important consequence of the pavement performance study was the development of pavement deterioration models to predict the different modes of distresses on pavements. These models are the first useful indigenous tools of its kind based on long-term pavement performance data under Indian conditions. These models have the capability to enable the highway engineers to assess the maintenance requirements of the highway network, project demand for the allocation of resources and to decide appropriate strategies for upkeep in a scientific manner. A software package 'PDM' has also been developed to provide an easy tool for making good use of the pavement deterioration models. This package calculates and tabulates the year-wise details of different modes of pavement distresses in future.

iii) Life Cycle Cost Analysis Study of Pavements

In this study a computer programme has been developed to compute the life cycle cost of pavements, duly considering the first stage strengthening cost, maintenance cost, user cost and salvage value during the design life of pavement. This programme has the capability to compute the life cycle cost for any design period and for any number of sections by varying the threshold serviceability level for maintenance. The effect of budget level on the pavement performance and penalties for deferred maintenance can also be quantified.

4.2.4. Development of PMS

i) Road Development and Maintenance Investment Decision Model (RDMIDM)

The updated Road User Cost Study and the Pavement Performance Study on existing pavements presented extensive indigenous research back up and basic relationships to develop a Total Transportation Cost Model for Indian conditions. The Road Development and Maintenance Investment Decision Model is an improvement over other indigenous

highway economic analysis packages. This is an updated version of the earlier developed Road Investment Decision Model (RIDM).

The RIDM model did not incorporate pavement deterioration relationships and also did not take into account the effect of periodic renewals on Vehicle Operating Costs (VOC). But the new updated model essentially incorporates updated VOC relationships and pavement performance and deterioration prediction relationships for Indian conditions, which enable the highway agencies to make a more accurate evaluation of economic benefits of highway schemes. The knowledge of pavement deterioration pattern together with the effect of maintenance cost on it, further improves the capability of the updated model to examine cost-effectiveness and timing of maintenance interventions. The model makes it possible to apply a rational approach in road maintenance decisions for obtaining best results from available funds. It has the capabilities to quantify the benefits of periodic maintenance, consequences of deferred maintenance, and cost effectiveness of maintenance strategies. Moreover, the model operation is simple and does not require very elaborate data input for its use. Of course, the major limitation of this model is its application at project level only.

ii) Development of PMS for Indian Highway Network

An R&D project entitled "Development of Pavement Management System for Indian Highway Network" has been completed at Centre of Transportation Engineering (COTE), Department of Civil Engineering, University of Roorkee. The methodology of PMS for a highway network has been developed using the data of identified test sections. Parameters considered for assessment of M&R needs of pavements are deflection, roughness, rutting, cracking and potholes, and the availability of resources for the choice of the type and thickness of materials for overlay. Investment needs for maintenance and rehabilitation of different pavement sections have been estimated based on the requirements of corrective and strengthening measures. It has been recommended in this study that before providing strengthening measures, corrective measures should be provided based on the criteria of excessive rutting, cracking and potholes on the pavement sections. The findings of this study would be used for developing standards for PMS for different categories of roads.

iii) Pavement Management System for Urban Roads

In this study, a 'prototype' PMS for urban roads has been developed, collecting traffic and pavement condition data on a number of road sections located in different areas of Delhi. This study deals with the second-generation investments related to pavements, i.e. investment needed through the lifetime of the road after its initial opening to traffic. The output of this study provides the prioritization of the road segments to be taken up for maintenance on the basis of 'Net Present Worth' method of economic evaluation.

iv) PMS for State Roads in Andhra Pradesh and Tamil Nadu

In the year 1991, for the very first time in the country, a computerized Pavement Management System for State Highways and heavily trafficked Major District Roads was introduced in Andhra Pradesh and Tamil Nadu. M/S John Burrows and Partners, UK were the consultants and the Asian Development Bank (ADB) provided the financial and technical assistance for this project. A customized version of HDM III along with a traffic statistics database was used as PMS software in this study.

v) National Highway PMS

This project was taken up in States of Karnataka and Uttar Pradesh with the objective to develop a computerized PMS for the National Highways. The Asian Development Bank (ADB) provided all the financial and technical assistance for this project. Initially, it has been installed on a pilot basis at the MOST. Later on it is proposed to be extended and implemented in all States. The system used for this project is called NETTER-PMS (HDM III with additional features). The limitations of this system are as follows :

- The validity of relationships of pavement deterioration, non-motorised congestion and vehicle operating costs are not studied in detail.
- The PMS cell operated separately from the regular maintenance teams (which are responsible for maintenance planning and management) despite the fact that integration was necessary. Also, communication between different parts of the state organisations was hampered because of poor office facilities and preoccupations with rank and status affecting the ability to communicate properly.
- In the two States where study was undertaken, the data collection was managed in different ways. Excepting axle load data, others were collected by PWD staff in Karnataka. Most of the items were sub-contracted in U.P. resulting in a difference in the way of presentation of results for their applicability. A relatively smaller, but, well trained team collected the visual condition data in Karnataka, whereas, in U.P. a number of groups within their own circles were used and were mainly untrained. This was due to the problem faced by the consultants in UP in delegation of training and inspection.
- Information for cost data was not up-to-date.

vi) Four States PMS

The project was directed primarily towards instituting network level PMS in the four States of Bihar, Maharashtra, Rajasthan and Uttar Pradesh. The study included selected sections of State Highways, Major District Roads and Other District Roads, which are managed by these States. The application system adopted for this project is called dTIMS (Deighton Total Infrastructure Management System). The ARAN (Automated Road Analyser)

was used as standard equipment for pavement roughness evaluations and Portable Fallin Weight Deflectometer "LOADMAN" was used as standard equipment for structural evaluatio of pavements.

vii) Gujarat Rural Road Maintenance Planning Study

This Project covered both paved and unpaved roads of Gujarat State comprising o State Highways, Major District Roads, Other District Roads and Village Roads. Internationa Development Association (IDA) provided technical assistance and RITES & CRRI provide consultancy for this project. The system is based on HDM-III applications. Th HDM-III model has been calibrated from the one time data of selected Gujarat roads an data available from previous pavement performance studies in India. During this study, network level maintenance planning system for Gujarat Rural Roads have been develope which includes a computerized road information system based on an objective dat collection scheme with provision of updation and further refinement and a decision suppo network.

viii) Maintenance Management Study for Rural Roads in Three Districts o Maharashtra

The study was completed by CRRI for the three districts of Maharashtra, viz., Pun Raigarh and Yavatmal. The rural road network comprising Major District Roads, Oth District Roads and Village Roads of total length 15,255 was covered for development o a Maintenance Management System. A data base on pavement inventory and condition o the road network was developed. A window based software "Maharashtra Economi Analysis" was developed on maintenance planning, km-wise, for a five year period wit economic analysis and prioritisation. The limitation of this system are as follows :

- This system is applicable only for the conditions prevailing in three districts o the Maharashtra State under the study.
- System is developed only for two types of soils, i.e., black cotton and moorun
- Maximum traffic volume (commercial vehicles) covered is of the order of 49 vehilces/day.
- Only one type of surface, i.e., premix carpet is covered under paved roads i this study.

ix) BMRDA Urban PMS

A simplified system for the maintenance management of road network in Bangalo was developed. A simple approach to arrive at the most economical Pavement Maintenanc Management System (PMMS) strategy has been suggested based on pavement evaluatio and other data. The pavement maintenance strategies based on the principle of PMM could result in considerable saving in road user cost and overall transportation cost a compared with the age old method of taking up maintenance work of each road link a and when found unavoidable. However, the studies on PMS for urban roads in India ar limited.

5. DATA BASE REQUIREMENTS FOR MMS

5.1. Identification of Data Requirements for MMS

With a view to optimally use the resources, the use of scientific tools has been duly recognised. Pavement Management System (PMS) is one such tool which enables engineers to decide priorities and strategies for upkeep of roads. Development of a PMS for any category of roads would require a Data Bank and Pavement Management Information System (PMIS) involving huge amount of data collection. While part of the data, especially on road inventory and road condition may be collected using automated data acquisition systems, other data, such as, on socio-economic features, cost, traffic, etc. can be collected manually or through secondary data sources, like, PWD records, schedule of rates, MOST cost data books, census reports, etc.

Many road administrations often follow a practice of collecting very large amount of data, but making a very limited use of the same for analysis and decision-making. The cost of data acquisition can be very high and is often the most expensive aspect of implementing and operating a pavement management system. Clearly, data should only be collected where their need can be justified. As such, it is essential that relevance, appropriateness, reliability and affordability of the data be ascertained if cost-effective results are to be obtained.

5.2. Significance/Importance of Data Base

One of the major inputs in the maintenance planning tools is the data base on various aspects which affect the maintenance decisions. A reliable and comprehensive data base is key to success of any pavement maintenance management system. All decisions on road investment are based on the quality of the database available. The selection of data items is most important part of a database development . Special care must be taken to ensure that only essential data items are included and that the specific users or uses for each item are clearly identified. A non-reliable data can lead to improper decisions and wastage of resources. The present condition of the road is necessary for prediction of future condition through application of various tools.

To be most effective, the data base for MMS should :

(a) provide for future expansion and/or modification as needed by the user

(b) include easy communication between central data repository and remote offices that may only need a small sub-set of data for analysis.

(c) be based on a location reference system that is able to link all data to a physical location

(d) allow quick and easy adhoc analysis and reporting in addition to the standard report

(e) be flexible enough to allow several output formats including graphs and tables that are required by the user.

(f) be compatible with the available hardware of the user organisation.

5.3. Elements of A Data Base

A pavement management system is very complex and puts together the elements of efficient data generation and storage, understanding of pavement maintenance operations, location referencing systems, optimisation techniques, economics and computer applications. The fundamental elements of importance in a data base are:

i) Maintenance work programmes
ii) Budget and resource allocation
iii) Scheduling of works
iv) Quality standards
v) Reports and performance reviews

5.4. Requirements of Data Base

In general four types of data are required for development of any PMSS. The data base of a PMSS will ultimately contain a large amount of data in each of the following types :

(1) Pavement inventory data
(2) Pavement monitoring data
(3) Cost data
(4) Other special data

The data base should have one block for each type of data and each block should further have several files, one for each data item. A beginning for selection of data items can be made by preparing a comprehensive list of all potential classes and types of variables of data used in each phase of MMS. This list can be subsequently modified depending on the requirements of the works, resources and the personnel available for data collection.

The various data inputs needed for development of MMS are shown in Fig. 5.1.

5.4.1. Pavement inventory: The data comprising category of road, its length width, surface type, thickness of different layers, etc. the historical data on year of last major activities (rehabilitation, widening, etc.), surface condition prior to last major activity, materials used from part of the inventory data. It also contains data on curvature and gradient (Rise/fall) per km length. This data is collected through office records and making use of equipments, like, gyroscope and gradometer. The most commonly used and simple method for identifying location is based on highway/project number, section and mileage.

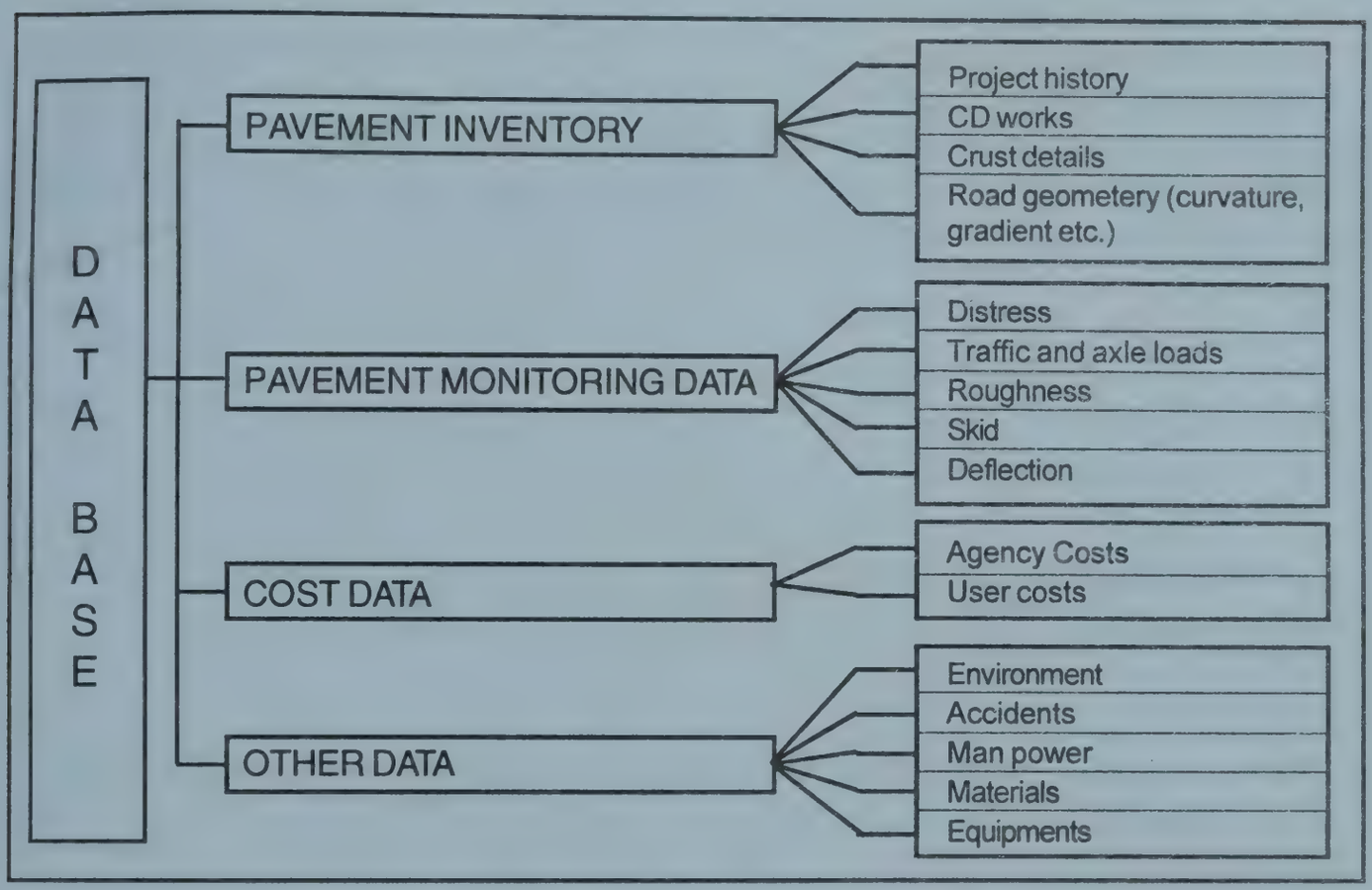


Fig. 5.1. Data Base Requirements for PMMS

5.4.2. Pavement strength: The structural capacity of the pavement is expressed in terms of rebound deflection or modified structural number (MSN).

5.4.2.1. Pavement deflection: It is the indication of load carrying capability and service life of the pavement under the expected traffic conditions. The structural capacity of pavement is a function of the material types and the thickness of different layers in pavement structure. The most commonly used equipment in India is Benkelman beam for this purpose. Falling Weight Deflectometer and Load Man are also used for specific cases.

5.4.2.2. Modified structural number : It is calculated as follows :

$$MSN = SN + 3.51\ (\log_{10} CBR) - 0.85\ (\log_{10} CBR)^2 - 1.43$$

Where, MSN = Modified Structural Number
SN* = Structural Number
CBR = Subgrade Strength determined in the laboratory at field conditions

* *Structural number is defined as an index number derived from an analysis of traffic, road– bed soil conditions and regional factors that may be converted to thickness (D_1, D_2, D_3 .....) of various layers by use of suitable layer coefficients (a_1, a_2, a_3.....) and is given by, $SN = a_1D_1+a_2D_2+a_3D_3+.....$*

5.4.3. Pavement condition data: It is the most important data needed for deciding upon the maintenance strategies and about which the road user is generally concerned. The basic measurement of pavement condition is existing distresses. The information required is on the type, severity and amount of distress. The following types of distress are to be considered :

1. Alligator or fatigue cracking
2. Longitudinal and transverse cracking
3. Bleeding
4. Depressions
5. Pothole
6. Patching
7. Ravelling
8. Rutting

5.4.4. Roughness: It is a distress form which is caused by the interaction of the above modes of distress and the quality of construction. It is defined as the irregularities in the pavement surface that adversely affect riding quality, safety and vehicle maintenance costs. There are a number of equipments available for measurement of roughness. The most commonly used equipments in India are Towed Fifth Wheel Bump Integrator and Vehicle Mounted Bump Integrator. These equipments are mechanical and response type which undergo changes in characteristics with passage of time and need to be calibrated periodically.

5.4.5. Traffic: Traffic is another important parameter to be considered for deciding upon the maintenance and rehabilitation strategies. Traffic is normally characterised in terms of equipment single axle load (ESAL) which is taken as 8.2 T. The data collection comprises of traffic volume and axle load studies. Vehicle Damage Factor (VDF) is the term used for categorising the damaging effect of the vehicle on the pavement. The damaging effect of the axles normally goes by the fourth power law.

5.4.6. Skid resistance: It is the indication of slippery/smoothness of the surface. The skid resistance of the pavement depends on the type of aggregates used in the surface course. This can be measured using portable pendulum type skid resistance tester.

5.5. Cost Data

This includes construction cost, maintenance cost, and rehabilitation cost. This data can be collected through secondary data sources, like, PWD records, schedule of rates, MOST cost data books, etc.

5.6. Other Special Data

This includes accident data, environmental data (temperature, rainfall), policy related data (budget, M&R), etc. This data can be collected from police, meteorological departments and other concerned organisations.

Other Special Data for Urban Roads

In addition to the above data, for urban roads the following data is required to be collected :

- Drainage details
- Details about service lines
- Footpath details

6. EQUIPMENT FOR DATA COLLECTION

6.1. General

Increased road wear created by growing traffic volume and increased axle loads has caused highway authorities to focus on the need to develop more cost effective maintenance management systems for road networks. Up-to-date information on pavement condition is essential to evaluate the maintenance requirements. Road maintenance constitutes one of the most important components of the entire road system, yet it is by far the most neglected one, particularly in developing countries where paradoxically it is needed the most. Traditional methods of pavement inspection rely heavily on the subjective assessment of road inspectors. These are slow, expensive and subject to considerable variability on the interpretation of defects. At present, the structural evaluation of pavements in India is being done by conventional tests, viz., Plate load test and Benkelman Beam. The functional evaluation of pavements in terms of roughness is done by majority of the agencies using towed Fifth Wheel Bump Integrator. These methods are relatively slow and call for frequent calibration also for response type equipment, like, Bump Integrator.

Advances in laser optics and ultrasonic technology have encouraged the development of remote sensing and have created the potential for measuring pavement condition objectively and quickly. With the development of robust and powerful microcomputers, with large data storage capacity, this potential has been realised in automated equipment that can measure surface characteristics at traffic speeds. As confidence has grown in this new technology's capability and reliability, many countries have made substantial advances in the development of quick measuring systems. These recent advances have reduced the operating and processing costs associated with the collection of condition data for maintenance management systems, and a number of quick measuring systems are now in operation throughout the world. This will continue to be an area of rapid change.

The technological developments are expected to make pavement maintenance management systems more powerful and more accessible at all levels within highway organisations. Advances in computer speed, storage, and networking are making access to these systems easy and economical for engineers, planners and researchers. Further, amongst the large scale research projects now underway in several countries, in several projects improved pavement performance prediction relationships are being developed. These will make future pavement maintenance management systems more reliable, and provide a sound basis for assessing the long-term, life-cycle consequences of various maintenance strategies. The increased usefulness and reliability of these systems will continue to stimulate improvements in the pavement evaluation equipment.

6.2. Types of Pavement Evaluation

The pavement evaluation has basically two parts.

1) Structural Evaluation
2) Functional Evaluation

To make additional inputs in data base required for MMS studies, studies on axle load spectrum, traffic, general inventory, etc. are also required.

6.2.1. Structural evaluation: The structural evaluation is undertaken to assess the pavement's structural ability to receive the loads plying over it. This is also needed to design maintenance and rehabilitation measures to meet the future requirements. The evaluation is generally carried out either by destructive or non-destructive testing procedures. The destructive methods are time consuming and require the pavement structure to be disturbed and hence cause inconvenience to the road user. On the other hand, the non-destructive methods do not require opening of pavement and easy to conduct and hence are more preferred. Amongst the non-destructive methods, deflection based evaluations are better.

6.2.2. Functional evaluation: The functional evaluation is being conducted to assess the riding comfort and safety over the pavement section as experienced by road users. Important among the functional indicators are the surface evenness and smoothness resulting in bumpy riding and skidding respectively. The distresses in the form of cracks, potholes, ravelling are also included in the functional evaluation.

6.3. Different Types of Equipment/Devices used in Structural Evaluation

Practically, all non-destructive evaluations for pavement's structural capacity are performed with deflection measuring devices. These can be placed in three broad categories:

1) Static devices which measure the pavement's response to a static load or a single application of a slow moving load.

2) Vibratory devices which measure the pavement's response to a vibratory or cyclical load

3) Impulse devices which load the pavement by dropping a known mass through a known distance and measure the response of the pavement.

6.3.1. Static devices: This category includes the following:

i) Benkelman beam
ii) Automatic Benkelman beam
iii) Curviameter
iv) Curvature meter

The details of some of the above mentioned equipments are described in the following sections.

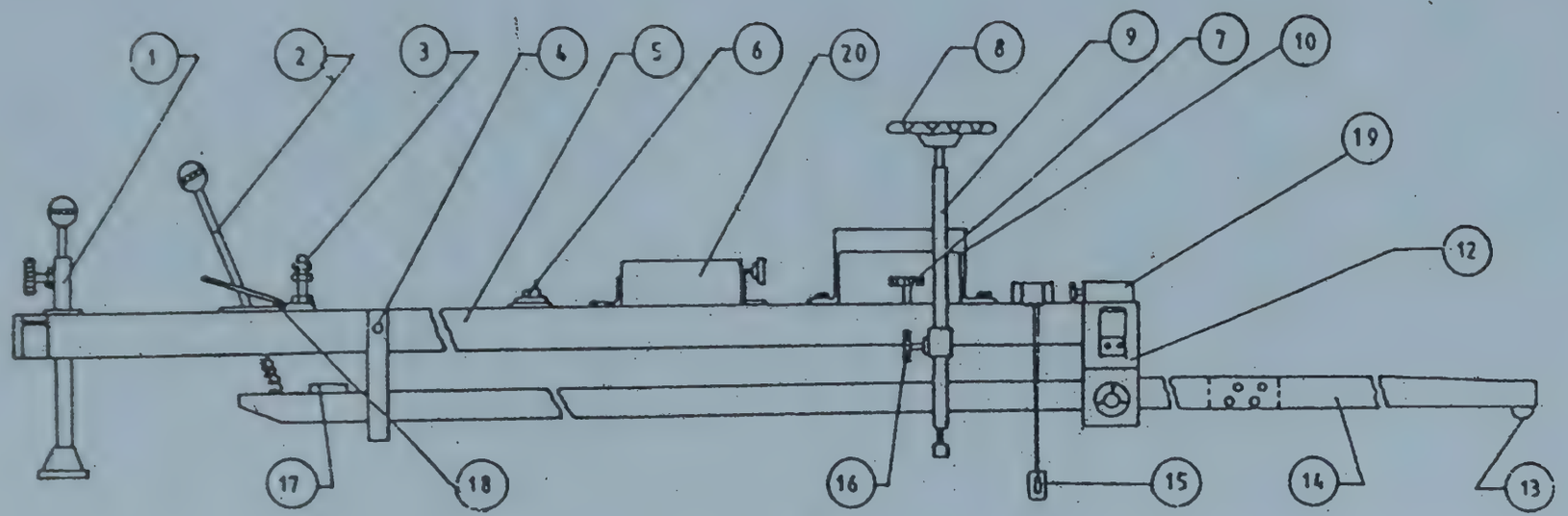
6.3.1.1. Benkelman beam: The Benkelman beam is a simple and in expensive device for deflection measurements. It was developed at the WASHO Road Test and has been used extensively by highway agencies for pavement research, evaluation and overlay design around the world. The Benkelman beam consists of a simple lever arm attached to a light weight aluminium frame. Measurements are made by placing the tip of the beam probe between the dual tyres of a loaded (8.17 T rear axle) truck at the point where deflection is to be determined. As the loaded vehicle moves away from the test point, rebound or recovery movement of the pavement is measured by the dial gauge. Measurements can be made either by WASHO or CGRA method. The equipment is versatile and simple to operate. However, it is slow and labour intensive. In some cases, particularly on strong pavements, the supporting legs may be within the deflected area resulting in influenced measurements.

Fig. 6.1. shows schematic diagram of a Benkelman Beam

6.3.1.2. Automated benkelman beam: Automated deflection beam device, which operates on the same principle as the Benkelman Beam, has been developed to increase the speed of deflection measurements. Deflection beams are mounted on the loaded vehicle. The beams are positioned and maximum deflection recorded automatically from test point to test point while the operator drives the truck along the pavement.

6.3.1.3. Curviameter: The Curviameter is an instrumented truck intended for measuring pavement deflection under a moving wheel load. The rear axle load can easily be varied from 80 to 130 kN. It allows a relatively rapid and continuous measurement of the deformation of the pavement along a wheel track, starting one meter in front of the moving twin-wheels load and ending four meters behind the wheels. This entire deflection bowl is digitised in a hundred samples (spaced 4 cm) and stored for each measurement. The geometry of the Curviameter has been designed to prevent influence of front axle on measurement. Temperature of air and that of the pavement surface are stored for each measurement.

The transducer used for detecting deflections is of the geophone type. Three of these are loosely fixed at equally spaced intervals along a 15 metres closed loop



S.N.	DESCRIPTION
1	REAR ADJUSTABLE LEG
2	TRANSIT CLAMP
3	DIAL GAUGE BRACKET
4	GUIDE BRACKET
5	SUPPORT FRAME
6	SPIRIT LEVEL
7	LOCKING PIN
8	ADJUSTMENT KNOB
9	LEVELLING LEGS

S.N.	DESCRIPTION
10	LIFTING HANDLE
12	BEAM SUPPORT
13	PROBE
14	BEAM
15	PUSH BUTTON SWITCH
16	ADJUSTMENT SCREW
17	DIAL GAUGE REST
18	CLAMPING PLATE
19	BUZZER
20	BATTERY BOX

Fig. 6.1. Benkelman Beam

chain. This chain passes between twin-wheels which load the pavement, each geophone being successively deposited at the pavement surface while the truck is running. A servo system ensures that the movement of the chain is well synchronised with that of the truck avoiding any skidding of the transducers. This is further more ensured on curves and for changes in longitudinal pavement slopes. Deflections are obtained by transforming the geophone signal into an equivalent acceleration response which is in turn double integrated. The transducers are calibrated daily against a known standard.

6.3.2. Vibratory devices: This category includes the following:

i) Dynaflect
ii) Road Rater

The details of these equipments are given below:

6.3.2.1. Dynaflect: The dynaflect is a light load, fixed-frequency device. It consists of a force generator and five geophones housed in a small two-wheel trailer. A remote control and readout panel is carried in the towing vehicle, which allows operation from the driver's seat. The load is generated by two counter-eccentric masses rotating at 8 Hz. The peak of dynamic load is 1,000 lbs (453 kg) distributed between the two load wheels. Five geophones mounted on the trailer tow bar at 12" (304.8 mm) intervals measure the deflection basin.

6.3.2.2. Road rater: The Road Rater is a vibratory device capable of varying both the load magnitude and frequency. Magnitude of the static load is varied by transferring the weight of the trailer from the travel wheels to the deflection load plate. To generate the dynamic load, a mass is hydraulically raised and lowered. The deflection load plate provides the reaction point for displacing the mass. Hence, as the mass is lifted, the deflection force is increased and as the mass is lowered, the deflection force is released. Four velocity transducers are used to measure the deflection of the pavement one at the centre of the load plate and the three placed at 1 ft (304.8 mm) intervals.

6.3.3. Impulse devices: This category includes the following:

i) Falling Weight Deflectometer
   a) Dynatest FWD
   b) Kuab FWD
   c) Phoenix FWD

ii) Loadman

6.3.3.1. Falling weight deflectometer: The deflection device that is receiving much attention now-a-days is the Falling Weight Deflectomer. In principle, this is a very simple device which consists of a weight which falls on a set of rubber buffers that is mounted on a circular foot plate with a diameter of 300 mm. Fig. 6.2 gives a schematic representation of the loading and the resulted typical deflection basis. From the description given above, it is clear that FWD produces an impact load. The shape of the load pulse is more or less a half sine, and the duration of the pulse is about 25 milli seconds. The deflections are measured in the centre of the loading plate as well as at various distances from the plate. Normally, 7 geophones (velocity transducers) are used, the velocity signal received by geophone is integrated once to obtain the vertical displacement. With respect to the loading plate, it is mentioned that in principle this is a stiff plate. At the bottom of the plate, however, a rubber mat is glued to ensure full contact between plate and pavement to ensure uniform stress distribution under the loading plate.

6.3.3.2. Dynatest FWD: In this equipment, factory calibrated geophones are used to register peak deflections. The operating sequence is completely automated. Pulse loads between 1500 to 27000 lb (7 to 120 kN) are produced with the model 8000 FWD. The model 800 FWD produces pulse between 6500 to 19000 lb (30 to 85 kN). Optional features available with various Dynatest FWD models include automated pavement temperature sensing, and automated air temperature sensing.

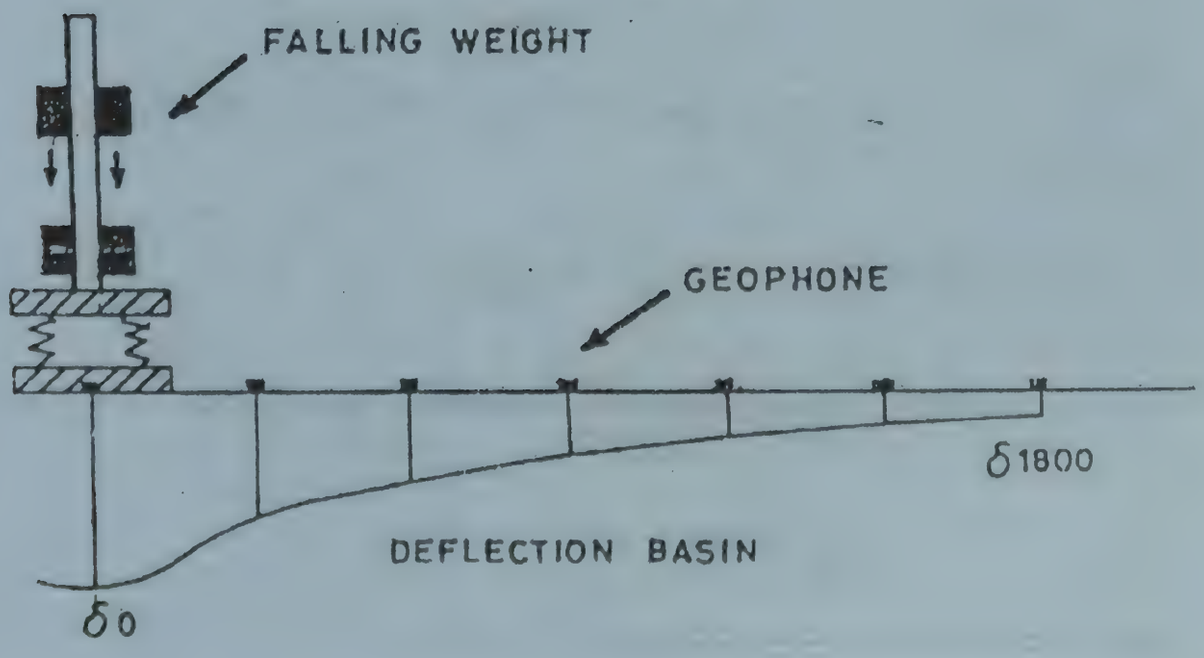


Fig. 6.2. Schematic Representation of Loading and Resulted Typical Deflection Dbasing

6.3.3.3. Phoenix FWD: The Phoenix model ML 10000 produces a dynamic impulse load range of 2300 to 23000 lb (10.2 to 102.3 kN). It includes three or six deflection transducers in adjustable mounts along an 8 foot (2.4 mt) raise/lower bar. The electronic control system consists of a micro-computer, control software, and sensors, options include IBM-PC micro-computer, air and surface temperature measuring devices, and a paint marking system.

The Phoenix FWD trailer features a protective metal housing and covering for the falling weight assembly, which includes a cylindrical mass (in nine sections) of maximum 660 lb (300 kN). The impact is transmitted *via* rubber pads over the load plate.

6.3.3.4. Loadman: The Loadman is a portable pavement testing device derived from the Falling Weight Deflectometer (FWD). The structure of the instrument consists of an aluminium tube containing a free moving weight. A circular plate at the bottom of the tube is used as loading surface. The equipment is operated by placing its base on the surface of the pavement layer and then activating the electronics, which drop the weight and record all relevant data. The results obtained from the Loadman are based on theories relating to stresses in a homogenous mass, to calculate the vertical stress at any point in any layer when the surface is subjected to a point load. The results give deflection and a mean modulus which is a measure of E-modulus.

The loadman is reported to give good results against which pavement condition may be evaluated especially for unbound surfaces and thin pavement structures.

6.4. Different types of equipment/devices used in functional evaluation

The different measures of functional condition are:

- Distress
- Roughness
- Skid resistance

6.4.1. Multi function pavement evaluation equipment: The different equipment used are:

i) Automatic Road Analyser (ARAN)
ii) Laser Road Surface Tester (LRST)
iii) PASCO Road Recon System
iv) High Speed Road Monitor (HRM) and Multi-function Road Monitor (MRM)
v) System of Inspection of Routes by Analysis Numerical and Optical (SIRANO)
vi) South Dacota Profilometer

vii) Automatic Road Image Analyser
viii) ROADMAN
ix) VIDEOCOMBO
x) DYNATEST Distress Meter

The details of some of the above mentioned equipments are described in the following sections.

6.4.1.1. Automatic road analyser (ARAN): This equipment has been developed in Canada. The system consists of a high speed camera in the front of a measuring vehicle which takes oblique pictures of the pavement through the wind screen with one or two high speed cameras at the back of the car taking vertical pictures of the pavement surface. The video images of camera 1 can be used for inventory survey purposes as well as broad visual condition surveys while the images of camera 2 can be used for detailed surveys. For data retrieval and processing system, a special panel is used. Processing of data is still performed by surveyors who interpret the video images and use the rater keyboard for entering the data into the computer. Although, the system allows fast collection of data, the data reduction and interpretation is still done by hand. This equipment is capable of performing the following functions:

- Longitudinal profile/unevenness, based on responses of ultrasonic sensors and accelerometer.
- Transverse profiles and rut depth, based on responses of a number of ultrasonic sensors housed in a mounting on the vehicle bumpers.
- Curve radius
- Surface distress, through video recording.

In order to be able to perform these measurements, a cross bar containing ultrasonic sensors is mounted in front of the vehicle and two gyroscopes are built in the vehicle. The cross bar has a standard length of 6 ft but this length can be increased to 12 ft to allow transverse profile measurements to be made over the entire lane width. At its maximum width, the bar contains 13 sensors. The profile is measured by sending ultrasonic sound pulses to the pavement surface and by measuring the time difference between sending and receiving.

6.4.1.2. Laser road surface tester (LRST): This equipment has been developed at Swedish Road and Traffic Research Institute, Sweden. The LRST is an advanced computer and laser based measurement system. The laser system consists of eleven lasers located on a bar that is mounted across the front of the vehicle. The outer most laser at each end of the bar is directed outwards at an angle of 50 degrees. This results in a measurement width of 3.2 m, eventhough the measuring bar is not more than

2.5 m wide. With two additional lasers mounted above the bar and also angled at 50 degrees, the measurement width can be extended to 4.0 m.

The LRST measures (i) transverse profile of the road, (ii) rut depth, (iii) roughness, (iv) cracking and (v) texture. Four of the lasers are specially designed to measure cracks and texture. Vehicle movement is compensated for by extremely accurate accelerometers. In addition to these objective measures, numerous subjective parameters can be entered manually by the operator during measurement and thus be stored directly with the normal LRST data. Such subjective information may relate to LRST measures or be totally independent. Common subjective information include edge cracking outside the range of lasers, pavement type, bleeding, or unusual measurement conditions.

The measuring principle is that a laser beam is projected towards the ground and reflected to a receiver. The point at which the reflected laser beam hits a light sensitive surface describes the distance to the road surface. Such measurements can be made at high speed because of the camera's high sampling rate. Each receiver samples the reflected laser beam 32000 times per second. The LRST is a flexible measurement system that can be used in both dense, slow moving traffic as well as fast traffic upto 90 kmph.

6.4.1.3. PASCO road recon system: This equipment has been developed by Pacific Aero Survey Company (PASCO) in Japan. It is capable of operating at night. This produces a continuous film strip recording of the pavement surface and a measure of roughness. Photographs are taken at night with controlled amount and angle of lighting. A hair line optical bar can be projected onto the pavement surface to provide a reference line for evaluating rut depth. The vehicle can be operated at speeds upto 50 kmph and photograph an area of 16 feet wide. Evaluation of pavement distress requires manual interpretation of photographs. A special viewing table facilitates the data reduction. This equipment has been used in the SHRP-LTPP study.

6.4.2. Roughness measuring equipment: The different equipments used are:

i) Towed Fifth Wheel Bump Integrator
ii) Vehicle Mounted Bump Integrator
iii) Micro Processor Based Bump Integrator
iv) Dipstic (Auto Read Road Profiler)
v) FHWA Profilometer
vi) APL Profilometer
vii) Profilograph
viii) Longitudinal Profile Analyser
ix) Abay Beam

The details of some of the above mentioned equipments are described in the following sections.

6.4.2.1. Fifth wheel bump integrator: The Bump Integrator consists of a trailer of a single wheel mounted within a rectangular steel frame. The wheel is of pneumatic tyre of a standardised size of 6.00 x 16 (4 ply). The wheel is carried on the centre of the axle by a pair of taper rolling bearings which can be adjusted to prevent end ply. The wheel itself supports the chassis through two leaf springs anchored to the front and shackled to the rear end of the frame through ball bearing fixtures. The ends of the axle are locked up by means of clamp blocks on the centre of the two leaf springs.

Its operation speed is 30± 2 kmph. It gives aggregate value of surface irregularities through electromagnetic signals. It makes speedy assessment of riding quality of pavement surface. The diagrammatic sketch of BI is given in Fig. 6.3.

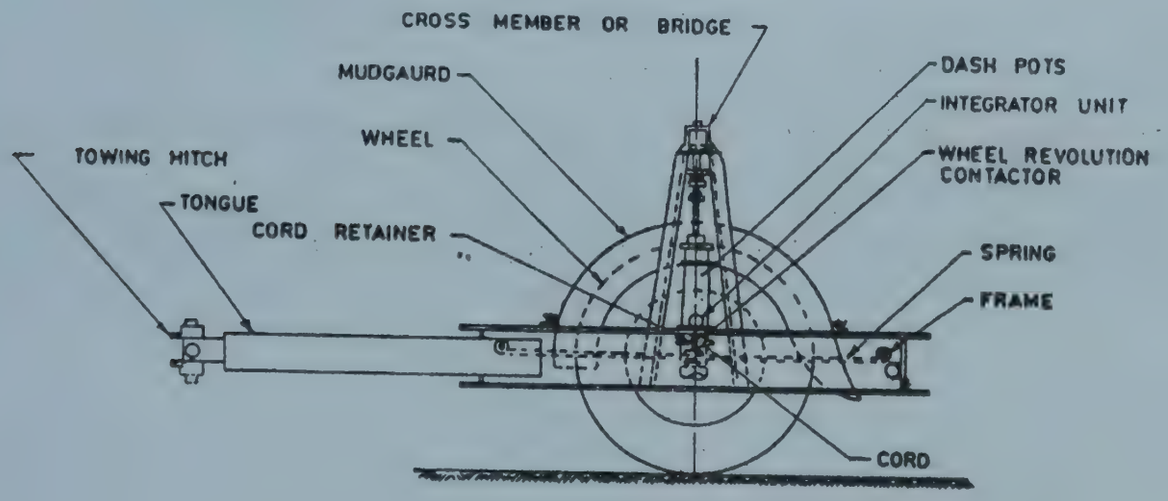


Fig. 6.3. Diagrammatic Sketch of the Bump Integrator

6.4.2.2. Vehicle mounted bump integrator: The car mounted integrating unit is the same as the integrating unit provided in the towed fifth wheel bump integrator. A cable is taken from a fixed point on the rear axle of the vehicle and is wound around a pulley forming part of the integrating unit. The integrating unit is located in the floor of the dicky of the car. The cable is wound around the pulley for about 2 ½ turns after initial tensioning. The differential movement between the rear axle and the body (dicky floor) due to road unevenness is measured by the upward vehicle motion of the wire which is transmitted into unidirectional rotary movement into electric pulses and recorded through the counters.

There are two counters together with a switch located in the instrumentation panel. Any one of the counter can be used at a time. It is advantageous to have two counters so that while one of them is in use, the other one will display the number of integrated counters in the previous km. The counter is powered by 12 V car battery itself. At the time of taking measurements vehicle was run at a speed of 30 ± 2 km/ph. Fig. 6.4 shows BI unit fitted in the car.

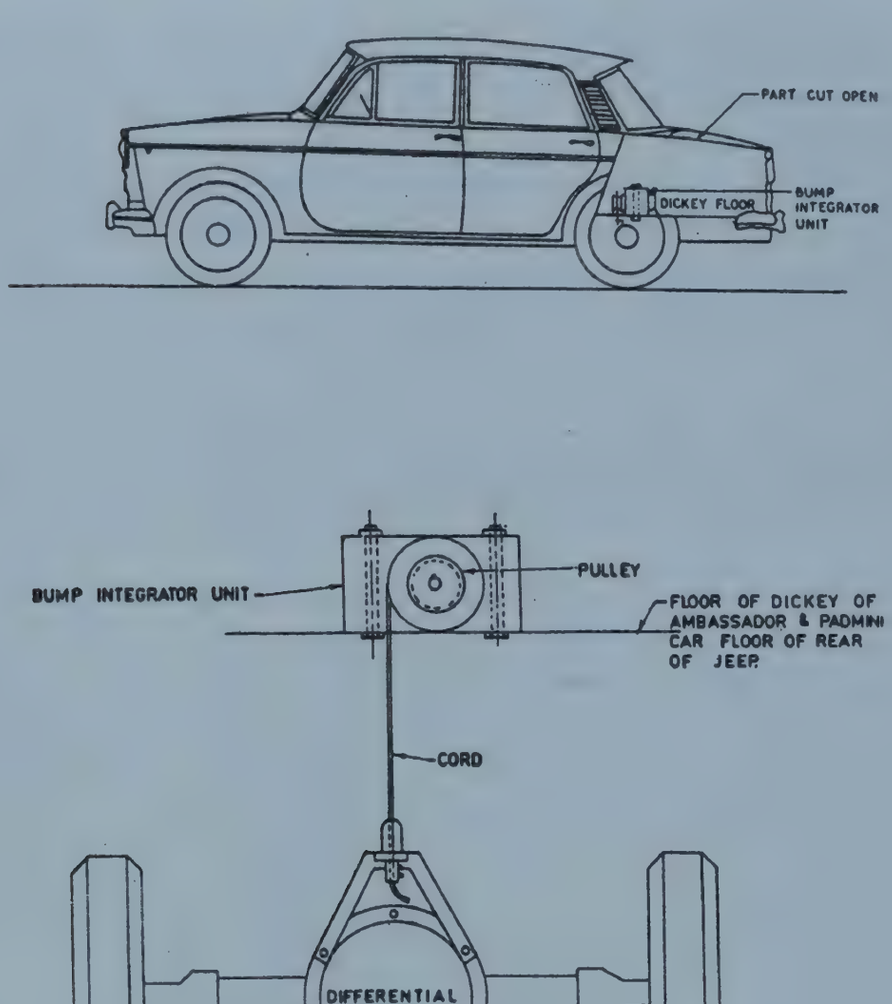


Fig. 6.4. Bump integrator unit fitted in the Car

6.4.2.3. Profilograph: This equipment has been developed at Danish Road Institute, Denmark. The profilograph is a specially designed passenger car equipped with 17 lasers which make it possible, at normal driving speeds, to get an exact registration of the road network's profile and surface condition. The profilograph is a standard passenger car which is equipped with measuring devices and designed for the specialised measuring jobs in the desired area.

The laser equipment, composed of 17 lasers, is placed on the front of the car on a beam measuring 2.47 m. Two of the lasers are angled, making it possible to measure a collective road width of 2.9 m. The lasers measure the distance between the beam and the road surface. Merely by taking one simultaneous reading from the 17 sensors, the road's cross profile in-relation to the beam can be determined. With several simultaneous readings by the sensors, the roads cross-profile, side slope, horizontal curves, length profile and vertical curves can be determined. The measuring accuracy is within 0.5 mm. With the help of the cross profile it is possible, among other things, to detect rut and their size.

With the help of the length profile, one can get road evenness, expressed among other things, by the so called IRI (International Roughness Index).

By using faster lasers and special print cards it is possible to determine the road surface's macro and micro texture. These measurements can be used as an indicator of road structure's friction and noise problems.

The distance measurer and the gyro which are placed on the beam, determine the car's exact position. Data from the distance measurer, gyro and lasers are stored in the car's computer. The PC processes these three sets of data, and by combining these it is possible to get a complete description of the road's course. The distance to the road is measured from the angle at which the laser beam is reflected back to the reader.

6.4.2.4. Longitudinal profile analyser: This equipment has been developed by 'Laboratorie Central Des Ponts et Chausses' in France. This consists of two scanning trailers which follow the normal wheel tracks of vehicle using the road. The two scanning trailers are towed by a vehicle travelling at a constant speed.

Measurement of the angular displacement of each of the scanning wheels of the APL trailers with respect to an inertial reference pendulum. This pendulum has a relatively low natural resonant frequency <1Hz. The range of measurable irregularities varies from $\pm$ 0.3mm to $\pm$ 100 mm.

The longitudinal evenness is represented by calculating the mean areas (depressions and bumps) of the mean deviations of the profiles recorded in both measuring tracks from a reference line formed by the smooth profile.

6.4.2.5. Dipstick (Auto Read Road Profiler): The Dipstick is a fully integrated data collection and processing system that measures and records road profiles accurately and quickly. In less than an hour, a person can measure, record and analyse upto 600 equally spaced co-linear evaluation points to an accuracy of $\pm$ 0.15mm per reading. Dipstick surveys take less than half time and are more accurate than optic and laser surveys. The data analysis in Dipstick is fully computerised.

The Dipstick profile stands on two support legs. The operator simply runs the Dipstick along a survey line alternatively pivoting the instrument about each leg. The digital display shows the elevation difference between the Dipstick's support legs, which automatically records and gives an audio signal.

The 'Roadface' software is included to calculate and print various profile statistics including the International Roughness Index (IRI) and the surface profile using straight edge.

Roughness is generally measured by response type road roughness measuring

systems (RTRRMS) which, with passage of time and usage change their characteristics. This results in the need for a periodic calibration of such response equipment. Dipstick is an instrument which measures the true profile and is a standard unit used for calibration of the response type equipment. This also can be used to measure the true profile of very short stretches.

6.4.3. Skid resistance measuring equipment: The different equipments used are:

i) Portable Pendulum Skid Tester
ii) Mu-Meter
iii) Skid Trailer
iv) Odiliograph
v) Sideway Force Coefficient Routine Investigation Machine (SCRIM)
vi) ASTM Standard Locked-Wheel Trailer
vii) SAAB Friction Tester
viii) Stuttgarter Reibungnesser
ix) Grip Tester

The details of some of the above mentioned equipments are given in the following sections.

6.4.3.1. Portable pendulum skid tester: It is a simple equipment used for measuring skid resistance of pavement. It is a dynamic pendulum impact type tester for measuring the resistance offered by a surface under test. It consists of a spring loaded standard rubber slider mounted at one end of the pendulum arm, sliding over the surface under standard conditions. It is used for measuring spot values of surface friction at representative locations. Though, it provides good information on the skid resistance of the pavement, it cannot provide data with different speeds.

6.4.3.2. Mu-Meter: It consists of a small trailer unit containing two freely rotating testing wheels inclined at an angle of 7.5 degrees to its direction of travel and inflated to an air pressure of 0.71 kg/cm^2 and a third central straight moving wheel. The device is towed by a vehicle at a constant speed of min 64 kmph under static load of about 80 kg. Mu-meter is used for the measurement of sideway force coefficient of friction. The device has an Automatic Printout Unit (APU) which gives digitised average sideway force coefficient of friction for the test section under dry and wet condition of the pavement. Besides the digitised value of the APU unit, surface friction value is also available in the form of a profile as recorded in the form of a continuous chart/graph for the test section.

6.4.3.3. Skid trailer: This equipment has been developed at Road and Hydraulics Engineering Division, Netherlands. The measuring wheel is mounted between the two wheels of the trailer. The load on the measuring tyre is 2 kN and the tyre pressure is 200 KPa. The tyre is the PIARC measurement tire (size 165-R15). Measurements are performed at 50 kmph with a wheel slip of 86 per cent. During the measurement a water film of

0.5 mm in thickness is sprayed in front of the measuring wheel. On airfields higher speeds are used and a water film thickness of 1mm is applied. Water supply is provided through a water tank in the towing vehicle.

6.4.3.4. Odoliograph: This equipment has been developed at Belgian Road Research Centre. It is easy to handle and permits a wide range of test speeds. It can be used on cross-town links as well as on motorways and airfield runways. The equipment consists of a measuring wheel with a hydropneumatic suspension, mounted at the centre of a vehicle. The device is independent of the vehicle and slides on two vertical columns. The hydropneumatic suspension of the measuring wheel and a height corrector make it possible to maintain a constant load of 270 kgs on the ground. The slipperiness of road pavements is measured by forcing a measuring wheel to roll in a direction which forms an angle to the direction of the carrying vehicle.

Apart from the sideway and vertical forces, the Odoliograph continuously records:

- the temperature of the wet pavement
- the vertical acceleration of the wheel
- the test speed

6.4.3.5. Sideway force coefficient routine investigation machine (SCRIM): This equipment has been developed by the Transport and Road Research Laboratory U.K. (Now TRL) to provide a routine method of measuring the resistance to skidding of wet roads. The test apparatus is fitted to a commercial vehicle chasis carrying a water tank. The standard machine has the test wheel mounted on the rear side of the vehicle in order to test the rear side wheel track with the least interference to other traffic. The test wheel, fitted with a standardised 3.00 × 20 tyre, has an independent load and suspension system and is inclined at an angle of 20 degrees to the direction of travel.

The water outlet on SCRIM has an elliptical cross section of 5.5 cm^2 area and wets the road in front of the test wheel for a width of approximately 300 mm. The water jet is gravity fed from the tank and the value has been calibrated to deliver sufficient water to provide a mean film thickness of 1.1 ± 0.1 mm on a smooth road. The sideway force developed is measured by a transducer and vehicle speed is measured by a pulse generation driven directly from the vehicle transmission.

This equipment uses the sideway force method of measuring resistance to skidding, the alternative braking force being less suitable for routine measurements. A freely rotating test wheel fitted with a standard tyre is inclined at a large enough angle to the direction of motion of the vehicle to generate the maximum sideway force on all surfaces requiring testing and to be in sensitive to small changes in angle when the vehicle turns. A smooth test tyre is used to eliminate any effects due to the wear of tread patterns. The ratio of the force developed at right angles to the plane of the wheel (the sideway force) to the load on the wheel is the sideway force coefficient (SFC). The main advantages of this

method of measurement are that a continuous record of resistance to skidding is obtained and the test tyre has a reasonably long life. Tests are normally carried out at 50 kmph, but SCRIM is capable of measurements at speed of upto 80 kmph.

6.5. Axle Load Studies

These studies can be conducted either by:

- Static Wheel Weigh Pads
- Weigh-in-Motion System

The details of these equipment are described in the following sections.

6.5.1. Static wheel weigh pads: These wheel weigh pads are portable, can be easily transported to any site and installed in the field without much time. The main components of the system are:

i) The platform with weighing mechanism, viz., load cells/load bars/special fluid filled tubes
ii) Connecting cables
iii) Indicating unit
iv) DC power supply

The weighing platform consists of two high quality cover plates of metal/alloy having high stiffness and anti-corrosive properties. Load bars or load cells or special fluid filled tubes are sandwiched between these cover plates. The weighing pad is connected to the indicator unit which gets power supply through a portable source capable of providing smooth DC supply (maintenance free rechargeable battery). The load cells/load bars have a metal body with foil strain gauges cemented to the body. The digital indicator gives the instant display of load.

6.5.2. Weigh-in-motion system (WIM): There are two types of WIM systems that are currently available globally. One system is permanent type and the other one is portable.

6.5.2.1. Permanent WIM system: There are a number of permanent WIM systems available. Basically, in a permanent WIM system two weighing platforms rectangular in shape, with slight variation in dimensions from manufacturer to manufacturer, are embedded in the road surface by cutting grooves at appropriate places. Apart from these, there is vehicle detection loop and one platform is located in each wheel path, with associated electronic monitoring system placed on the roadside. Some systems use strain gauge load cells while a few others use oil-filled piston which acts as a load cell.

Apart from this there are permanent WIM systems that use peizo weigh sensor, which has a length of peizo electric cable mounted in a U-section channel and encapsulated in the resin. The sensor is set into a slot cut across the traffic lane, with its top face level with the road surface. The burried loop vehicle detector is installed adjacent to the sensors. The entire system when installed gives information on axle load, vehicle classification, gross vehicle weight, vehicle speed, vehicle count, vehicle length, etc.

6.5.2.2. Portable WIM system: The piezo-electric strip sensors provide axle load data. The WIM equipment is automatic weighing and vehicle classification equipment for use at normal highway speeds. The system is capable of measuring vehicle loads and speeds on roads upto four-lane width. The WIM is a micro-processor based. The WIM interface and data base computer system provides link with the road sensors. The data collection system is compatible to any computer and stores vehicle records. The user defined reports can be down loaded to an office computer through a floppy diskette. The equipment operates on solar energy or battery powered system.

The roadside electronics can also be housed in the experimental van and moved from site-to-site, as required. The van houses the hardware of the WIM system including solar panel. Besides these the other items useful for continuous work of the staff in the field are also housed inside. The equipment records and provides the information on vehicle weight and axle loads, and speed identification for speed and weight violation, etc. The equipment stores the following information related to the site and the traffic; site details, time and date of passage, vehicle index number within the collection period, vehicle speed, vehicle classification, weight of each vehicle, spacing of vehicles and vehicle length, etc.

The equipment is ideal for characterisation of 90-100 per cent vehicles even on heavy traffic roads.

6.6. Road Geometrics Studies

6.6.1. Vertical profilometer (Gradometer): The Gradometer equipment consists of a heavy pendulum. The displacement of the pendulum while moving along the gradient is amplified by a gear assembly. The pointer attached to the gear assembly moves on a graduated (18 per cent) semi circular disc to record the gradient through an electronic circuitry operating on a 12 V car battery.

The gradometer works in conjunction with the distance measuring device. The distance measuring instrument records the number of pulses at the rate of one per every 20 m. Simultaneously, with the recording of pulse at every 20 m on the distance measuring counter, the percentage gradient indicated on the graduated disc. is added and displayed on two sets of separate counters, one recording positive gradient (Rise) and the other recording the negative gradient (Fall). Using toggle switch, it is possible to select one set of counter at a time.

Since the cumulative value of the percentage gradient at every 20 m is recorded on the counters, the total rise/fall in any given length is obtained as follows :

$$\text{Rise /Fall} = \frac{20 \times \text{difference in counter readings}}{100}$$

$$= \frac{\text{Difference in counter readings}}{5}$$

For consistent readings, the vehicle is run at a fixed speed (around 30±2 km/ hr). Sudden jerks and speed changes are avoided.

6.6.2. Gyroscope/Gyrocompass: The Gyrocompass is flight instrument used for the navigation of aircraft. There are primarily two types of Gyrocompasses available :

i) operated on pneumatic principles
ii) operated on electricity

In the present guidelines the second type of Gyrocompass has been recommended, since the first type is not very much in use. The horizontal profile of the road is recorded with the help of this equipment. The device functions on 115 volts, stepped up from 12 volts of car battery through a static inverter, and continuously indicates the direction of vehicle movement. The stability of the instrument reading is achieved by a complicated system of mounting the unit with freedom about three axes. The Gyro unit is suspended on the gimbal rings so that it is free to move in three axes, a horizontal spin axis, a second horizontal axis at right angles to the spin axis and a vertical axis. The measurement of the angle is possible to an accuracy of two degrees. For initial "Zeroing" two knobs are provided. By pressing and rotating the Set Heading knob, it is possible to bring the inner circular metal plate marked with a pointer and matching reference to any desired position. Similarly, by means of the Synchronising knob the outer circular plate with degree markings (compass) can be brought to coincide with the reference mark. It is preferable to start with Zero reading at the beginning of the survey. Horizontal profile of road is measured by recording changes in the compass reading. Recording of compass readings together with distance counts at the beginning and end of curve enables measurements of deviation angle and length of curve. The formula used to find the radius of the curve is :

$$R = \frac{360}{(D^1 - D^2)} \times \frac{(N^2 - N^1)}{2} \times 20$$

Whereas,

R	=	Radius in meters
D^1	=	Gyroscope reading at the beginning of the curve
D^2	=	Gyroscope reading at the end of the curve
N^1	=	Distance measuring counter reading at the beginning of the curve
N^2	=	Distance measuring counter reading at the end of the curve

The multiplying factor 20 is because one distance measuring counter reading signifies a length of 20 meters.

6.7. Recommendations for Indian Studies

Some of the available equipments which are employed in data collection for a MMS are discussed in the above paragraphs. However, generally some of the equipments are used worldwide for a MMS study. The name such equipment, certain important features and recommendations with their suitability for Indian conditions are given in Table 6.1.

Table 6.1. Important Characteristics of Recommended Equipment for Data Collection

Name of Equipment	Principal of Operation	Output	Operating Speed	Multiple Measurement	Merits	Limitations	Recommendations
Benkelman Beam	Elastic deflection under static load	Rebound deflection at single point under load	Crawling	NA	Simple, quick, cheap	Single point deflection	Can be used for routine overlay requirements for all categories of roads
Falling Weight Deflectometer	Elastic deflection under impulse load	Deflection basin	200-300 stations per day	NA	Easy to operate, relatively fast, complete deflection profile is measured	Expensive	Recommended for use on primary / secondary road network
Loadman	Elastic deflection under impulse load	Single point deflection	80-100 stations per day	NA	Simple, portable	Single point deflection	Recommended on thin pavements with smooth surfaces subject to good correlations with already established methods
Automatic Road Analyser (ARAN)	Continued images one forward and two straight down	Video tapes	30-100 kmph	Distress (Crack, rut depth) profile, roughness, gradients, curvature, etc.	Covers about 600 km a day with good accuracy	Expensive, dry surface measurements, processing is manual	Recommended for use on primary / secondary road network with dry surface
Laser Road Surface Tester (LRST)	Measures slope profile in the time domain	Distress, unevenness, IRI long, Profile	Upto 90 kmph	Distress, Rut depth, profile, macro texture	Suitable for all weather conditions	Calibration needed daily for laser and accelerometer	Recommended for all categories of roads
Towed fifth wheel bump integrator/ vehicle mounted bump integrator	Response type measurement	Unevenness index	30 kmph	NA	Simple, reliable data collection	Can not measure profile, needs frequent calibration	Recommended for all categories of road

(contd...)

Name of Equipment	Principal of Operation	Output	Operating Speed	Multiple Measurement	Merits	Limitations	Recommendations
DIPSTICK	Measures vertical profiles by slope measurements	International Roughness Index (IRI)	Slow walking	NA	Measures true profile	Very slow	Recommended for more accurate surface profile measurements and for calibration of response type equipments (towed / vehicle mounted bump integrators)
British Pendulum Skid Tester	Measures lateral friction by swing action	Skid resistance	Very slow	NA	Simple and portable	Noting and recording manual, spot measure-ments only	Recommended for all categories of roads
Mu Meter	Measures side force coefficient	Friction value	Upto 150 kmph	NA	Requires little traffic control	Ineffective in winter, sharp curves and steep grades	Recommended for primary roads
Static Weigh Pads	Load measured through load cells/ load bars	Static loads	Normal	NA	Any traffic conditions	Vehicles need to be stopped and aligned	Recommended for medium and low traffic roads
Weigh-In-Motion	Peizo electric sensors and capacitor type sensor	Weights of moving vehicles	Normal	Speed, vehicle type	Traffic is not interrupted during studies	Proper calibration checks are required	Recommended for primary / secondary roads with smooth surfaces, steel rimed tyres should be avoided
Instrumented Car	Measurement of upgrade, down grade and directional change of vehicle	Cumulative rise / fall, curvature	32 kmph	Unevenness, gradients, curves	Capturing of more parame-ters in a single run	Low speed, sudden jerks adversely effect the results	Recommended for all categories of roads

7. METHODOLOGY FOR DATA COLLECTION

7.1. General

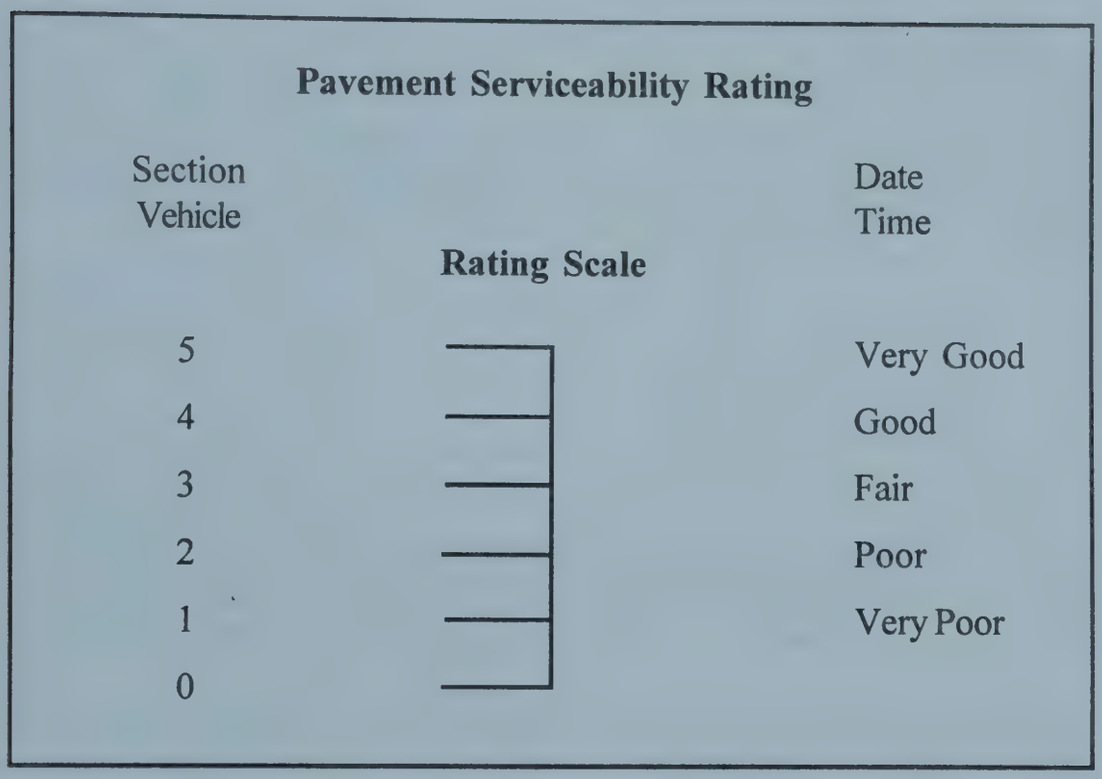
7.1.1. The different evaluation techniques and the various equipments available globally for use in data collection are discussed in Section 6. The suitability and applicability for Indian studies are indicated in Table 6.1. The methodology for data collection using the equipment presently in practice in the country for pavement evaluation which make inputs in a database required for development of MMS is described in the following sections. Also, methodologies for the data recordings which do not involve any of these equipments, but are a part of requirements, viz, distress observations, traffic data, test pit observations are also discussed.

7.1.2. Since the total road length involved in network is normally large, it becomes practically difficult to cover the entire network for creating data base for development of a management system. In such cases, it is advisable that certain representative length of the total road network is identified for detailed data collection. The length so selected is referred as core network and is used for development of base structure / framework of proposed maintenance management system. Pavement condition rating technique can be used for the assessment of the network condition in conjunction with the data base development for core network to enable planning of the maintenance strategies.

7.1.3. Pavement evaluation technique based on pavement serviceability rating (PSR) is a user oriented procedure, which recognises the basic fact that roads are primarily intended for the comfort and convenience of the road user. The utility of the serviceability rating technique of pavement condition evaluation in establishing user based priorities for strengthening and renewal of pavements is self evident as it would remove much of the uncertainty associated with fixing of priorities for road improvement/ maintenance works. It is customary to obtain visual ratings and to correlate with physical measured values from the core network. To facilitate the expression of condition in tangible terms, a suitable rating scale suggested in the following diagram may be used.

While recording the ratings, it is also recommended that the distress values given may be followed as a guide. In case of 'very poor' road sections, the various distresses/defects are noted to the nearest approximation, to facilitate inputs in the PMMS.

For identification of maintenance needs the road length in different categories of distress are conveniently grouped based on the ratings to decide the maintenance strategies. However, the roughness is measured for the entire network. The structural



Pavement Condition Rating Based on Different Types of Defects

Defects	Range of Distress, Per cent				
Cracking (%)	> 30%	21 to 30	11 to 20	5 to 10	< 5
Ravelling (%)	> 30%	11 to 30	6 to 10	1 to 5	0
Pothole (%)	> 1 %	0.6 to 1.0	0.1 to 0.5	0.10%	0
Shoving (%)	> 1 %	0.6 to 1.0	0.1 to 0.5	0.10%	0
Patch (%)	> 30%	16 to 30	6 to 15	2 to 5	< 2
Settlement and Depression (%)	> 5%	3 to 5	Up to 2	Upto 1	0
Rutting (mm)	> 50	21 to 50	11 to 20	5 to 10	< 5
Rating	1	2	3	4	5
Condition	V. Poor	Poor	Fair	Good	V. Good

evaluation is recommended to be carried out on highly distressed sections for appropriate corrective measures.

7.2. Pavement Inventory

The various data items to be covered under pavement inventory are given in Section 5.4.1. While the history of pavements is to be obtained from the local agency,

the other details are to be collected from the site. The details of CD works, and features, like, height of embankment and depth of water table, etc. can be noted. Crust details need to be obtained from test pit observations as explained in Section 7.7, later in this Chapter. The curvature and gradient details are measured using Gyrocompass and Gradometer fitted in the instrumented car.

7.2.1. Methodology: The methodology for measurements instrumented car is given below, while the equipment detail, have already been discussed in Sections 6.6.1 and 6.6.2.

- A speed of 32 kmph is maintained for better results.
- The values of distance measuring counter and gradient are recorded, preferably at every 500 meters, corresponding to 25 pulses of distance measuring counters.
- For curvature the gyrocompass and distance counter readings and beginning and end of each curve, are recorded to give length and degrees of curves.

The pavement inventory details are recorded on proformae 7.1, 7.2 & 7.3.

7.2.2. Calibration : The equipment fitted in the instrumented car need frequent calibration, as they tend to get influenced by usage and time. The calibration procedures for these equipment are given below :

7.2.2.1. Gyrocompass : It is to calibrate the Gyrocompass at frequent intervals. The vehicle is positioned stationary and the type position are chalk marked. The compass reading is noted and then the vehicle is turned through 360°C to be brought to the same original marked position. The compass reading is again noted, which is expected to be the same as that of initial reading. If any correction is required, it is to be carried out.

7.2.2.2. Gradometer : It is desirable to run the instrumented vehicle on a uniform gradient, with the criterion that the reading obtained on the plus gradient should be the same as the reading obtained on the minus gradient in a particular section. The above runs are made in the same stretch, one run for the positive gradient. When such a condition is achieved, the instrument is supposed to be adjusted so that it will record zero gradient on a horizontal level stretch and will record accurately the plus and minus gradients. At this point, the instrument is finally clamped.

7.3. Pavement Distress Measurements: Since these guidelines are for flexible pavements, the various types of distress in the following four categories are to be considered while conducting distress measurements.

(a) Surface defects : Fatty surface, smooth surface, streaking and hungry surface, etc.

(b) Cracks : Hairline cracks, alligator cracks, longitudinal cracks, transverse cracks, edge cracks, block cracks, etc.

(c) Deformations : Slippage, rutting, corrugations, shoving, shallow depressions, settlements and upheaval.

(d) Disintegration : Stripping, loss of aggregate, ravelling, potholes and edge breaking, etc.

7.3.1. Methodology: The areas covered under different types of distress are to be marked with chalk on the ground and each one measured separately, segment-wise, with measuring tape. The affected area is to be marked (left, centre right) in the form of rectangular figures. The length and breadth of the distressed area to be measured. In the case of single longitudinal and transverse cracks, the cracks length to be measured and effective width is to be taken as 30 cm.

7.3.2. Data Recording: The length and width of pavement surface having different types of distress are to be measured and recorded in the Proforma 7.4, alongwith the type and severity of distress.

7.3.3. Calibration : Not Applicable.

7.4. Riding Quality

The roughness measurements are to be taken with towed fifth wheel bump integrator or vehicle mounted bump integrator.

7.4.1. Fifth wheel bump integrator

7.4.1.1. Equipment : The equipment consists of a single-wheeled trailer, having a rectangular chassis within which a pneumatic tyred wheel is mounted. The wheel itself supports the chassis through two leaf springs anchored to the front and shackled to the rear end of the frame through ball bearing fixtures. Four electromagnetic counters, two each for recording of roughness and the distance travelled by the unit, fitted on the panel board, are put into electric circuit. The two dash pots are provided to serve as damping units and are filled upto required level with fluid of specified consistency, upto the required level.

The unidirectional movement between the axle of the wheel and the chassis is recorded by an integrating unit. This unit performs the function of closing a pair of contacts inserted in the circuit of electromagnetic counters, one for each mm/inch of integrated unidirectional movement. A wire, with one end connected to the chassis and the other end wound round a pulley, forms part of the integrating unit. The wire is wound around the pulley for about 2 ½ turns after initially tensioning it. For every 1 mm / 2.5 cm (1") of cumulative bumps, the bump recording counter registers one unit.

7.4.1.2. Methodology : The following procedure shall be followed while measuring roughness with fifth wheel bump integrator.

- Tyre pressure is maintained at 2.1 kg.cm^2 (30PSI)
- Damping fluid level is maintained at 3 cm below from top of collar
- Flexible cord is tightened by rotating 2 ½ rotations of integrating pulley
- Electrical connections are checked in static condition after providing connection to vehicle battery to ensure completion of circuitary
- Driver is instructed to drive at 30±2 kmph speed
- The fifth wheel bump integrator is run on all selected wheel paths for specified number of runs depending upon the importance of the roads

7.4.1.3. Data recording : At the beginning of the section, after setting the counters at zero, on/off switch is to be switched on. At the end of the section the observer change over to the 2nd set of counters. First set of counters need to be set at zero after noting the readings. The readings of integrating and wheel counters on km basis are to be noted in the Proforma 7.5.

The following precaution need to be taken during measurements :

(a) the speed of the vehicle is to be constant at 30+2 kmph. This speed has to be attained before reaching the section and maintained from some distance before reaching the section.

(b) for non-experimental running, the unit needs to be towed towing wheels.

Photo 7.1 shows general view of the fifth wheel bump integrator.

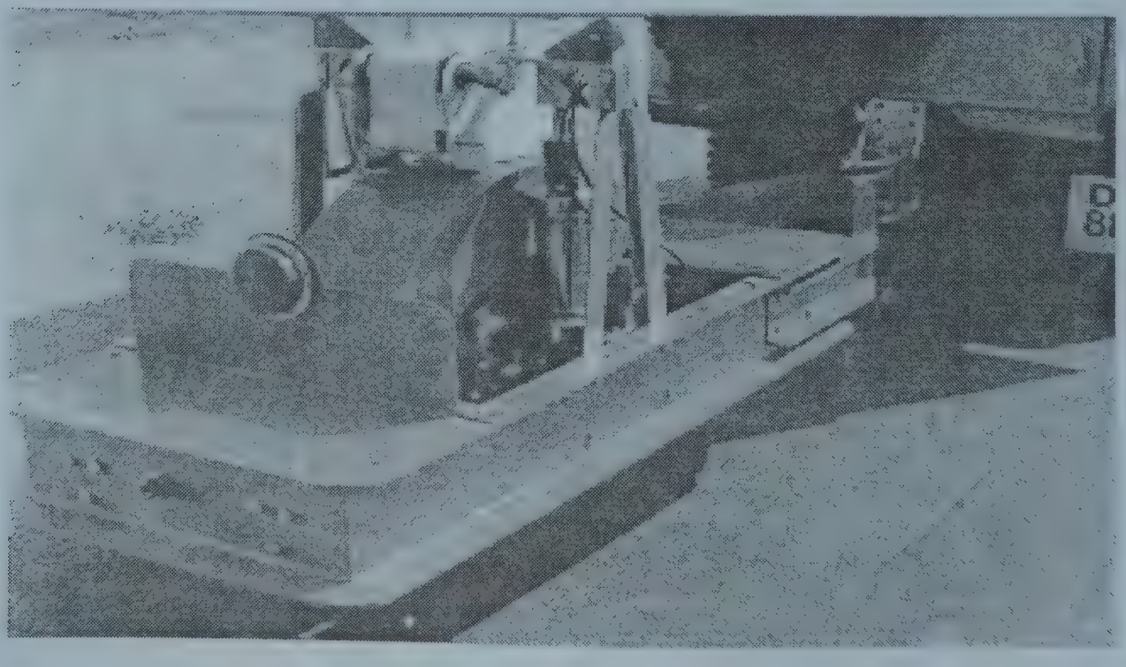


Photo 7.1. General View of Fifth Wheel Bump Integrator

7.4.2. Vehicle mounted bump integrator

7.4.2.1. Equipment : The vehicle mounted integrating unit is the same as the integrating unit provided in the fifth wheel bump integrator. The integrating unit is located in the floor of the dicky of the car. The cable is wound around the pulley for about 2 ½ turns after initial tensioning. The differential movement between the rear axle and the body (dicky floor) due to road unevenness is measured by the upward vehicle motion of the wire which is transmitted into unidirectional rotary movement into electronic pulses and recorded through the counters.

7.4.2.2. Methodology: The following procedure shall be followed while measuring roughness with vehicle mounted bump integrator.

- The vehicle mounted bump integrator fitted in the dicky of the car/jeep is checked for its 2½ rotary of pulley
- Connection at the bottom end of the car is checked for correctness
- Speedometer of the car is checked for its proper functioning
- Speedometer cable is checked for its free and smooth working
- Load on the car is checked, i.e., driver, one recorder and one technician
- Battery connections are checked for BI power supply
- At no point cable should be left hanging or coming in the way of sitting persons
- Driver is instructed to drive at 30±2 kmph
- The vehicle mounted bump integrator is run on all selected wheel paths for specified number of runs depending upon the importance of the roads

7.4.2.3. Data recording: It is same as in the case of Towed Fifth Wheel Bump Integrator.

Photo 7.2 shows the view of the unit housed in the dicky of the car.

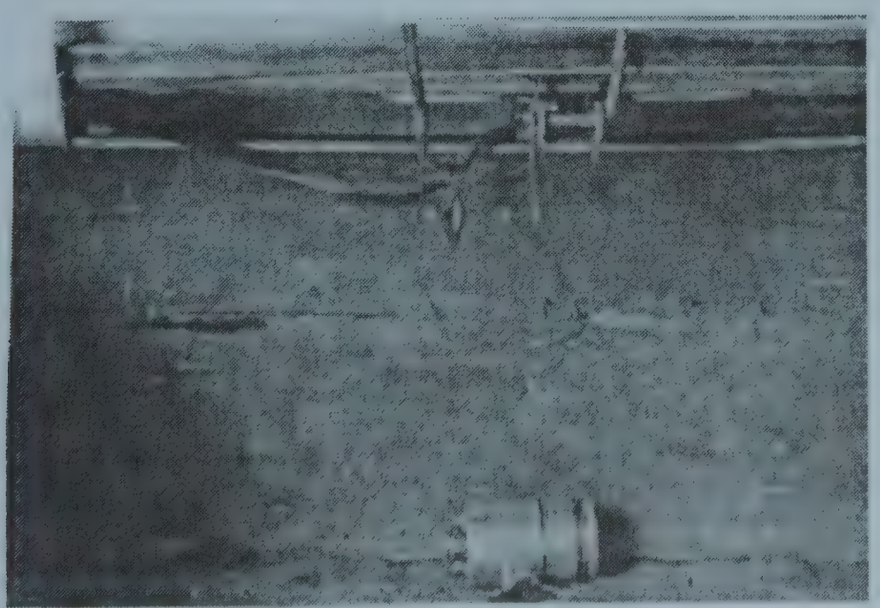


Photo 7.2. Vehicle Mounted Bump Integrator

7.4.3. Calibration: The towed fifth wheel bump integrator and vehicle mounted bump integrator shall be periodically calibrated, before/after the measurements with a standardised bump integrator kept only for the purpose of calibration of other bump integrators or with a computer based autoread road profiles, i.e., Dipstick.

The following procedure shall be used for calibration purpose :

- 10-12 Nos. of test sections of 100 m in length covering different roughness, ranging from 1500 mm/km to 10000 mm/km need to be selected.
- The fifth wheel bump integrator/vehicle mounted bump integrator which is to be calibrated needs to be run on selected sections and on all three wheel paths (outer, central, inner) as per the methodology mentioned above.
- The standardized bump integrator is to be run on the same wheel path as per the procedure mentioned above if the calibration is to be done with standardized bump integrator.

If the calibration is to be done with Dipstick, the following procedure shall be followed.

- 6 Nos. 9 v alkaline batteries are loaded into the Dipstick base unit after readying Pocket Computer
- After warming up the base unit is checked to its zero balance, it shall be zero balanced on a flat film clean surface
- After zero balancing the zero balancing knob is locked during data collection in the field. After the completion of zero balancing functioning of Dipstick or its calibration can be checked by using the calibration shim provided with the equipment
- Upon arrival at the site Dipstick is assembled including pocket computer PC-1600
- In each test section the identified three wheel paths are chalk marked
- Dipstick is run on the identified chalk marked three wheel paths
- Separate file is made for each test section
- Dipstick data is down loaded into office computer for calculation of IRI data
- For each section the IRI is calculated using Dipstick software

The calibration of B.I. with a standard BI or Dipstick is given in Proforma 7.6.

Photo 7.3 shows the general view of the Dipstick.

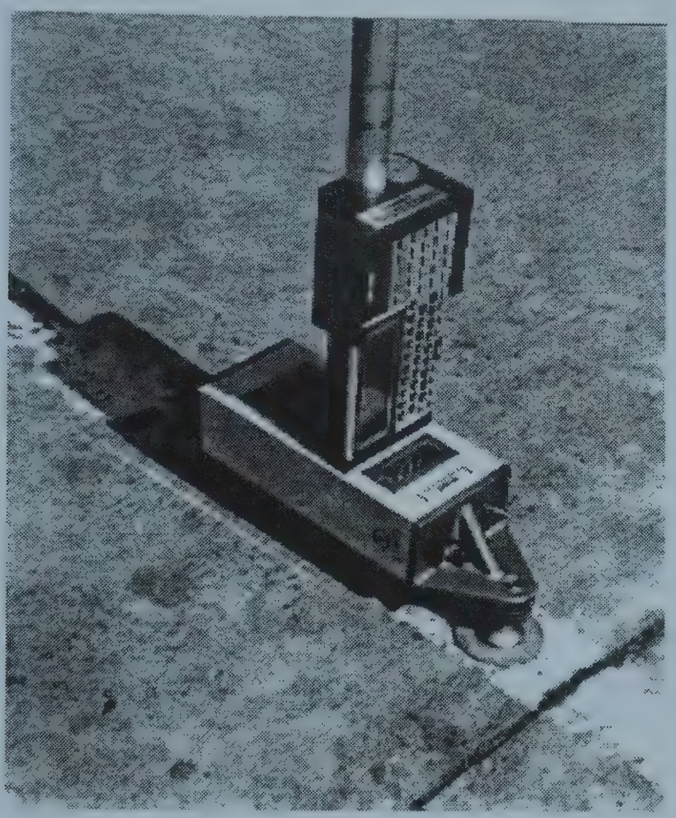


Photo 7.3. General View of Dipstick

7.5. Structural Evaluation by Non-Destructive Methods - Deflection Measurements

7.5.1. Equipment : The equipment shall include :

i) Benkelman beam

-	Length of probe arm from pivot to prove point	244 cm
-	Length of measurement arm from pivot to dial	122 cm
-	Distance from pivot to front legs	25 cm
-	Distance from pivot to rear legs	166 cm
-	Lateral spacing of front support legs	33 cm

ii) A 5 tonne truck is recommended as the reaction. The vehicle shall have 8170 kg rear axle load equally distributed over the two wheels equipped with dual tyres. Spacing between the tyre walls should be 30-40 mm. The tyres shall be 10 x 20, 12 ply inflated to a pressure of 5.60 kg/cm^2. The use of tubes and nib treads is recommended.

iiii) Tyre pressure measuring gauge

iv) Thermometer (0-100^{0}C) with 1^0 division

v) A tool for making 4.5 cm deep hole in the pavement for temperature measurement. The diameter of the hole at the surface shall be 1.25 cm and at bottom 1 cm.

7.5.2. Methodology

- The point on the pavement to be tested is selected and marked. For highways, the point should be located 60 cm from the pavement edge if the lane wide is less than 3.5 m and 90 cm from the pavement edge for wider lanes. For divided four-lane highway, the measurement points should be 1.5 m from the pavement edge.
- The dual wheels of the truck are centered above the selected point.
- The probe of the Benkelman beam is inserted between the duals and placed on the selected point.
- The locking pin is removed from the beam and the legs adjusted so that the plunger of the beam is in contact with the stem of the dial gauge. The beam arms are checked for free movement.
- The dial gauge is set to have approximately 1 cm free movement of stem. The initial reading is recorded when the rate of deformation of the pavement is equal or less than 0.025 mm per minute.
- The truck is slowly driven a distance of 270 cm and stopped.
- An intermediate reading is recorded when the rate of recovery of the pavement is equal to or less than 0.025 mm per minute.
- The truck is driven forward a further 9 m.
- The final reading is recorded when the rate of recovery of pavement is equal to or less than 0.025 mm per minute.
- In case of thick bituminous surfacings pavement temperature is recorded atleast once every hour inserting thermometer in the standard hole after filling up the hole with glycerol.
- The tyre pressure is checked at two or three hour intervals during the day and adjusted to the standard, if necessary.

All the measurements shall be done as per IRC:81-1997

7.5.3. Data Recording : The initial intermediate and final readings of dial gauge are to be noted. The test has to be repeated at each test point till three consistent readings are obtained. The condition of the test point is also recorded. Pavement temperature is to be measured and recorded every one at interval. All this data are recorded on Proforma 7.7.

Photo 7.4 shows deflection measurement set up in the field.

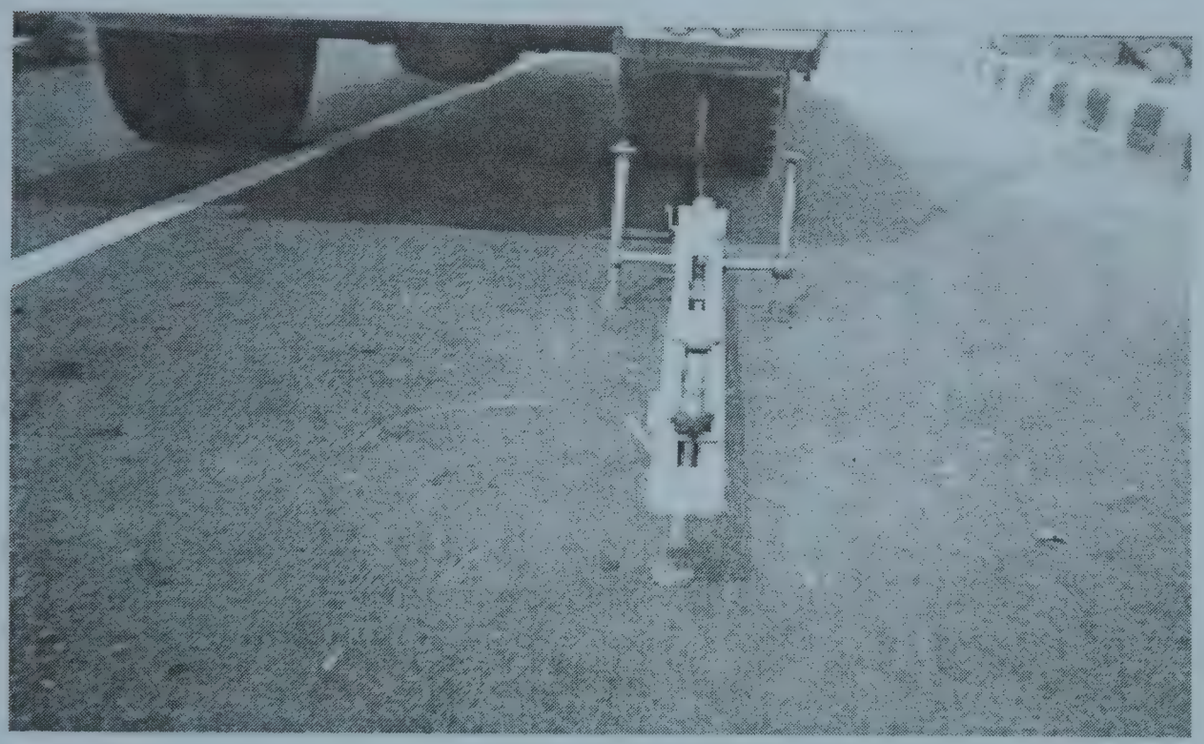


Photo 7.4. Deflection Measurement set up in the Field

7.5.4. Calibration

The Benkelman beam shall be calibrated before starting the deflection measurements to ensure that dial gauge and beam are working correctly. This can be done by using the procedure described below.

The beam is to be placed and levelled on a hard level ground. A number of metallic blocks of different thickness (measured accurately with a precision micrometer) with perfectly plane faces are placed under the probe and the dial gauge reading recorded each time. If the beam is in order, the dial gauge on the beam should read one half the thickness of the metallic block on which the probe was placed. Otherwise, the dial gauge should be checked and replaced if necessary. If the dial gauge is functioning correctly the beam pivot should be checked for free and smooth operation, secondly the striking plate beneath the dial gauge spindle should be checked to ensure that it is tightly secured and has become grooved by the dial gauge stylus.

7.6. Subgrade Moisture Content

The moisture content in the subgrade level varies significantly throughout the year due to many factors. The affecting factors are soil type and its level of compaction, pavement materials and their compaction level, surface condition, rainfall, temperature depth of water table and height of embankment, surface and sub-surface drainage, etc.

To findout moisture content, a pit of suitable size is to be dug on the shoulder adjoining pavement section, upto the subgrade level. Two samples of soil at 50 mm below subgrade top need to be taken out and immediately sealed in labelled sample tins/plastic containers to avoid evaporation. Subsequently, moisture content is to be determined as per IS : 2720 (Part-II) and recorded on Proforma 7.8. These values are used for applying seasonal Corrections to the rebound deflection data.

7.7. Structural Evaluation by Destructive Testing –Test Pit Observations

Structural evaluation of a pavement, as discussed in Section 6.2.1, can be carried out either by destructive or non-destructive procedures. The non-destructive method based on deflection is explained in Section 7.5.

The destructive evaluation method mainly involves opening up the road section to make useful observations. Test pit observations quite often serve as a meaningful method of destructive evaluation. A test pit of suitable size (1m x 1 m) is dug open upto subgrade level to get required information.

Normally, the exact number of test pits are decided depending upon the extent of network studied. The test pits shall be judiciously decided to cover different aspects, like, category of road, construction period, crust materials thickness, environmental conditions, traffic, etc. Minimum representative members of test pits are to be worked out for the data requirement, since digging open a test pit itself will contribute to create a weaker location on the road section.

After knowing the location, normally, a test pit of size 1 m x 1 m is dug open, vertically covering both original pavement and widened portion, if any. The pit should be dug to reach upto subgrade level. The subgrade soil is tested for in-situ density after removing top soil for about 30 cm. The soil sample is also collected for further laboratory evaluation, in sufficient quantity. The other pavement materials may also be collected if the study requirement demands for it. The thickness of various layers needs to be recorded by meaning at different locations of each layer and averaging out. The data is recorded in Proforma 7.9.

7.8. Axle Load Survey

The axle load surveys can be conducted either by wheel weight pads or Weight-in-Motion (WIM) system.

7.8.1. Wheel weigh pads: These are to be preferred where the traffic volume is low to medium.

7.8.1.1. Equipment: The static weigh pad should be made of high quality cover plates having high stiffness and anti-corrosive properties. The main components of the system should have:

i) The weighing platform (load cell or fluid pressure sensor based)
ii) Remote Display
iii) Connecting Cables
iv) DC Power supply (12 v)
v) Interface facility for data recording/printing

7.8.1.2. Methodology

- In case the data is required to be collected for both directions, i.e., Up and Down on a two-lane road staggered stations, two different weight stations, about 100 m apart for up and down traffic are established so that traffic flow is not disturbed.
- The weigh pad is seated at each location in a pit on rigid and firm base with its top about 5 mm above the surrounding road surface.
- The weigh pad is connected to the indicator and battery and checked for its proper functioning.
- Before start of work 8 to 10 vehicles with known weights are weighed first and using the calibration equation/factor the exact weight of such vehicles are calculated. The known weights and the weights so measured should be quite comparable. This exercise is needed to ensure the proper working of equipment prior to its use in the field.
- The vehicles to be weighed are stopped much before the weighing station (about 20-30 m) and driver is asked to move the vehicle towards weigh pad at creep speed after he has aligned the vehicle in the direction / position of weigh pad.
- The front wheel of the vehicle is brought slowly on to the weigh pad and wheel weight recorded from the digital indicator.
- Similarly, the rear wheel assembly is brought on to the weigh pad and wheel weight recorded. In case of multi-axle vehicles, all wheel assemblies are brought on to the weigh pad and wheel weights recorded.
- During weighing of the vehicle, care is taken to ensure that the wheels are on the weigh pad and there is no overhang of wheels outside the weigh pad.
- The data is collected for trucks, buses, light commercial vehicles and light passenger vehicles on sample basis, depending upon volume of traffic. Majority of the vehicles to be weighed are commercial trucks and the sample should be representative of axle load pattern witnessed on the road. However,

the vehicles to be considered for weighing and sample size is decided based upon the clients requirements

7.8.1.3 Data recording : The wheel weights (front, rear 1, rear 2, rear 3, etc.), vehicle registration No., type of vehicle, axle configuration (Fig. 7.1), etc. are recorded in Proforma 7.10.

Photo 7.5 shows the wheel weigh pad set up in the field.

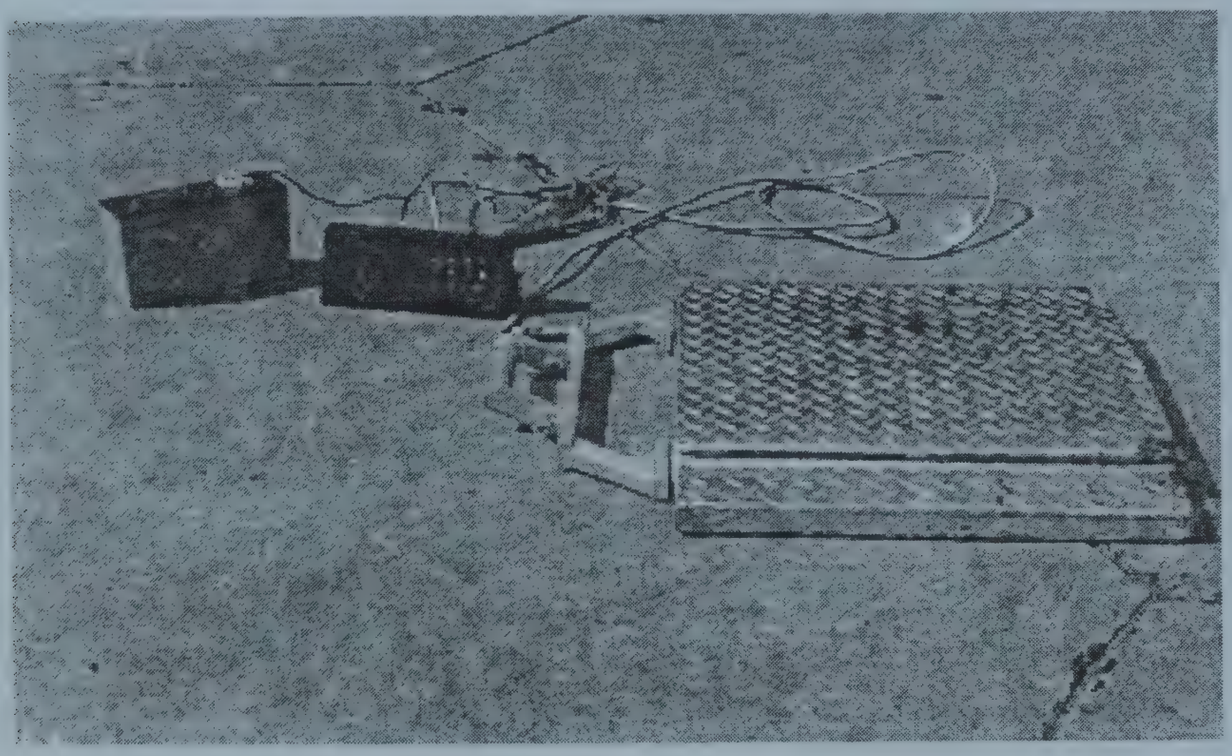


Photo 7.5. Wheel Weigh pad set up in the Field

7.8.1.4. Calibration : Before/after field survey, the weigh pads are to be calibrated as per the procedure. Calibration is to be done with load frame.

- Calibration is done preferably under 40 T load frame.
- The axle weigh pad is placed on a rigid base and load is applied by hydraulic jack through proper arrangement.
- The load is applied in increment of one ton.
- The corresponding load indicated by the digital indicator of the equipment is noted down.
- The loading is continued only till the indicator records maximum permitted load to be measured using the weigh pad.
- Using the information on load applied and load recorded by the equipment for different loadings, the calibration equation/factor is worked out.

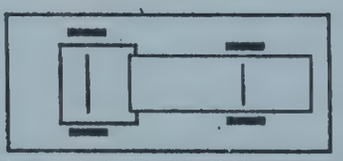
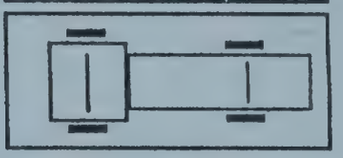
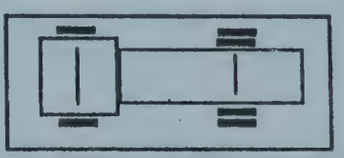
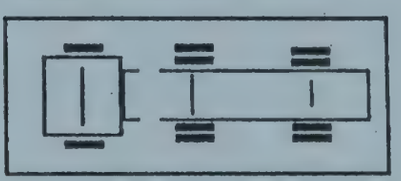
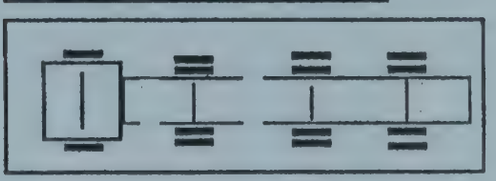
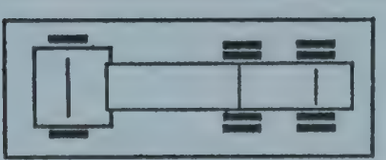
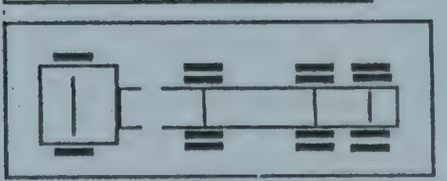
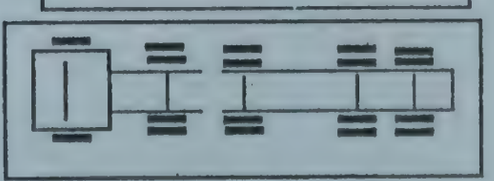
CODE	DESCRIPTION	CONFIGURATION
1.	LCV GOODS (Single wheeled rear axle)	
2.	LCV PASSENGER (Single wheeled rear axle)	
3.	2 AXLE TRUCK	
4.	BUS	
5.	SEMI TRUCK TRAILER (Single Rear Axle)	
6.	TRUCK TRAILER (Single Rear axle)	
7.	3 AXLE TRUCK	
8.	SEMI TRUCK TRAILER (Tandem Rear Axle)	
9.	TRUCK TRAILER (Tandem Rear Axle)	
1.A	LCV GOODS (Dual wheeled rear axle)	
2.A	LCV PASSENGER (Dual wheeled rear axle)	

Fig. 7.1. Vehicle Code Numbers for Different Axle Configurations

7.8.2. Weigh-in-motion system : This system is preferred for high density corridors.

7.8.2.1. Equipment : A portable WIM system consists of peizo weigh sensors and loop for vehicle detection. These systems can be easily transported and installed on the road surface. The peizo weight sensors are covered with a tape coat and the vehicle detection loops are nailed on to the road surface. Roadside electronics along with monitor and batteries are housed in a portable all weather proof cabinet. After the completion of the survey sensors alongwith loops can be easily removed from the road and moved to the other survey site.

In some systems weigh mats are provided. The weigh mat is used with two inductive loops. The weight sensor comprises of rubber and steelmat. Three sheets of steel, separated by soft rubber act as a three plate capacitor. Compression of the mat under load produces a variation in capacitance, which is interpreted as a weight by the attached microprocessor-based data collection system.

The main components of Portable WIM system are :

- Loop for vehicle detection
- Roadside electronics unit with inbuilt computer for data collection and storage
- Peizo sensors
- Roadside cabinet, solar panel, battery pack, data analyser unit

Photo 7.6 shows the field setup for axle load survey with weigh-in-motion system.

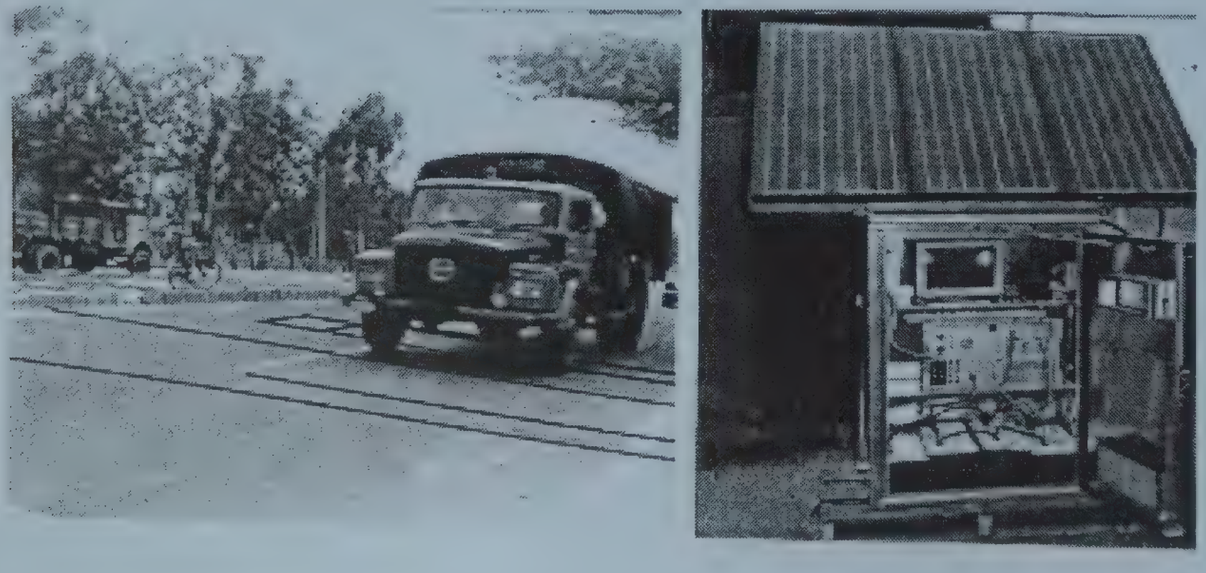


Photo 7.6. Field set up of Axle Load Survey with Weigh-in-Motion System

7.8.2.2. Methodology

- The site should be selected in such a way that the site should be straight and level road section with no stoppages before and after site upto 200 m. either side. The surface should be good without any distress including bumpiness.
- The hardware and software of the system should be checked before installation.
- Installation of the system should be done as per the procedure mentioned below:

- First of all loops and sensors are fixed on the road surface in staggered position so as to cover traffic in both directions in case of undivided carriageway. In case of four-lane divided carriageway the installation on the road is done in the similar way for both the directions. The WIM electronics cabinet for any one of the direction is placed strategically in the central verge along with the solar panels so that one set of WIM electronics work independent of the other. The solar panels are tied properly by fixing on the WIM cabinet with suitable ropes nailed in the central verge. For other direction WIM electronics will be housed in the experimental van.

The fixing of the loops and sensors in any lane is done in the following way.

- Loop is fixed on the road surface at a distance of 2 m from first sensor.
- Second sensor is fixed at a distance of 3 m from first sensor.
- As regards the other carriageway the same procedure is to be followed.
- The surface of the solar panels is covered with chicken mesh.
- The loops and sensors are numbered and are connected respectively to the specified slot in the WIM electronics.
- WIM electronics is started up and step-by-step operations are followed as per software manual.
- The software is installed and various information, like, power memory log, lane configuration, loop configuration, loop width sensor separation are fed step-by-step.
- Once the readings start appearing on the computer screen, it is closely monitored for one hour.
- If any corrections are needed in the software, i.e., in classification scheme or any other it is done and monitored for another one hour. To make such correction, placement distance loop width, etc. are fed into the computer with exact dimensions by referring the WIM software manual.
- Once the operations are found satisfactory with regard to response from the hardware and software the installation is taken as complete.

- After installation, the calibration of the system should be done as per the procedure mentioned below :

- An experimental truck is used for calibration whose weights are determined either on weighing scale (Dharam Kanta) or by using inhouse wheel weigh pads, duly calibrated.
- The experimental vehicle with known axle weights, axle separation, total length of the vehicle and a proper working speedometer is made to run on specified survey location for at least 15 times. The axle loads measured by taking average of 15 runs with the WIM system and the weights measured with static weigh bridges are compared and calibration factors calculated. These factors are fed into the computer under calibration menu. For doing so, it is necessary to refer the manual supplied with the system
- Taking the statistical average of all the above values each sensor is calibrated and new set of calibrated values are noted down in a hard copy and entered in the computer along with changes
- The calibration programme of WIM system is considered as accomplished after the above tasks are performed. The experimental vehicle is again allowed to make 10 runs as above, for fine tuning of the calibration

- The data, as per the procedure mentioned below needs to be collected

- Proper light arrangements with an additional generator if required, are made at site for working during night. Periodic checks on the system are carried out to see if any damages has occurred to the hardware set up (i.e., sensors and loop) while at site
- In case of any damage to the sensor, it is immediately replaced and a fresh calibration is carried out for that particular sensor
- The data collected for the first day is analysed in the field for ensuring proper working of classification scheme.
- In case classification scheme is not working properly, a note of it is made and checked in the office later on with ideal classification schemes devised for the purpose since the raw data collected is always available in the hard disk of the computer. Various reports are automatically produced as the system contains a customized office software.

7.9. Traffic Volume Survey

7.9.1. Methodology and data recording: Traffic surveys are to be conducted manually, for three consecutive days round the clock, by field teams by engaging adequate number of enumerators. Tally marks for different vehicles are put in the respective columns depending upon the composition of the traffic. For the fifth number, the tally marks are diagonally crossed. The data on classified volume are recorded in a standard Proforma 7.11. A separate count station needs to be established for each road.

8. METHODOLOGY FOR MANPOWER REQUIREMENTS, EQUIPMENT OPERATION, CALIBRATION, PERIODICITY OF UPDATING

In our country, there is no separate department or cell to look after the maintenance works exclusively, the department responsible for construction is also responsible for maintenance works. Broadly, this holds good for all categories of roads barring some village roads in a few States. As regards maintenance of National Highways, the Ministry of Road Transport and Highways provides the funds to get the maintenance works executed by the concerned State Governments. As a matter of fact, with an exception of the State of Tamil Nadu, all other State PWDs have the responsibility of looking after the works of buildings in addition to the road works.

The field work at the level of Junior Engineer as far as road maintenance is concerned, generally receives only divided attention. The Junior Engineer looks after surveys and collection of data in the shape of bar-charts, etc. which show the condition of different stretches of roads. These records indicate as to which particular section has received renewal or strengthening and when? A programme of maintenance is prepared on year- to-year basis and forwarded to the sub-divisional level and then on to the higher ranks and depending upon the maintenance allocations from the Chief Engineer, the maintenance programme is adjusted suitably. The strength of gangs for maintenance of different types of roads varies from State-to-State. However, the current practice is to reduce the government salaried employees. In such cases, it is found prudent to assign the maintenance of the roads on a contract maintenance packages. This will ensure the use of the best materials and latest machinery and a high quality assurance that will result in long lasting maintenance free pavements.

In order to scientifically regulate the maintenance activities and make use of the available funds in a best possible way, the maintenance management systems are the effective tools, for any implementing agency. The development of any PMMS involves data base development first, the requirements of which are mentioned earlier in Section 5. To build reliable a data base it is important to collect all the needed data of various items on inventory, condition, cost, traffic, etc. Also, information on the manpower requirement for data collection, equipment operation, the needed calibration and periodicity of updating of the data needs to be provided.

The manpower requirements for data collection of different items methodology for equipment operation, calibration and periodicity of updating are discussed here :

8.1. Manpower Requirements

It is obvious that some manpower is needed for collection of data in the field. In order to get a good quality and reliable data, an optimum size of the team is

necessary and the role and responsibility of members need to be defined. The manpower requirements at all levels, including data collection, compilation and interpretation to make inputs in further analysis need to be clearly indicated in the planning stage of the project.

8.2. Equipment Operation

Different types of modern pavement construction / maintenance equipment are widely used in the country now. However, the field engineers are not aware of the intricacies of the operation of these equipments so as to ensure the optimum performance by using these equipments. There is a need to train the engineers on several issues pertaining to the use of these modern equipments. Whenever there is a centralised facility, it is desirable to have identified operating and maintenance staff for the upkeep of equipment to derive maximum output.

8.3. Calibration

Calibration is the process of determining and quantifying the operation of any specific equipment in relation to a stable standard measure. For example, the output of response type road roughness measuring system is dependent on many factors related to the host vehicle (e.g., suspension system, tyre pressure, weight, wheel base, etc.) and the equipment itself. Therefore, calibration is necessary to convert the output of a particular equipment to a standard or universal measure. The calibration procedure requires the following steps.

1. Establishing a calibration course
2. Calibration of the system
3. Calibration control

8.4. Periodicity of Updating

There are certain data which do not change much with time, such as, road details. However, there are other data which tend to change with time and hence need updating. The integrity of database should be maintained by allowing only limited and selected persons to handle the inputs and modifications. The various data item that need to be updated include inventory, monitoring data and cost data.

The requirements of manpower for data collection, equipment operation, calibration and updation periodicity are given in Table 8.1.

Table 8.1. Requirements of Manpower for Data Collection, Equipment Operation, Calibration and Periodicity of Upgradation

Data Category	Data Item	Data Collection and Recording Method	Manpower Requiremnt for Data Collection Including Calibration and Equipment Operations (Number)*	Calibration	Periodicity of Updation (Years)	Remarks
Pavement Inventory	Road History, Geometry and Environmental	Information Collection in manual. Road geometry measured using equipment	2 for 200 kms/day	As specified in Section 7.2.2.	5	The detailed man power requirements indicated are for the measurement on core network. However, for the complete network, distress can be assessed visually by a team of trained persons (2 persons/ 200 km/day). The deflection measurements are to be taken on representative sections only.
	Crust Details	Manual	1 for 2 pits./day	–	5	
Pavement Monitoring	Distress	Manual Automated	2 for 2 km/day 3 for 300 km/day	–	2	
	Roughness	Automated (BI)	2 for 200 km/day	As specified in Section 7.4.3	2	
	Deflection	Manual (Benkelman beam)	2 for 5 km/day	As specified in Section 7.5.4	2	
		Automated (FWD)	1 for 15 km/day			
	Skid	Manual (BPPT)	1 for 10 km/day @ 3 spots/km.	–	2	
		Automated (Mu-meter)	2 for 200 km/day			
	Traffic	Manual	2 for each direction/shift**	–	1	
		Automated (TCC)	1 per location/shift**			
	Axle Load	Manual (Weigh pad)	2 for each direction/shift**	As specified in Section 7.8.1.4	2	
		Automated (WIM System)	1 for each direction/shift**	As specified in Section 7.6.2		
Cost Data	Agency User	Information-manual	1 for network in each C.E.'s office	–	5	
Others	Accident Manpower	Information-manual Equipment material				

* Skilled persons for field work only. Drivers and labour not included
** Shift is for 8 hours duration

BI : Bump Integrator
WIM : Weigh-in-Motion
FWD : Falling Weight Deflectometer
BPPT : British Portable Pendulum Tester
TCC : Traffic Classifier and Counter

9. DATA BASE DEVELOPMENT

9.1. General

The development of information system / database is of paramount importance for any management system. Roads and road transport, which are life line of any country, can not be an exception to it. To satisfy the road and road transport infrastructure requirement in consonance with its developmental phase, decisions shall be based on more reliable updated, relevant, easily accessible and affordable information. Ideally, the data required for reconstruction and preservation of existing facility shall be readily available to facilitate the management to decide upon policy related issues.

Road upkeep/maintenance related database, in general, involves a wide variety of data, such as, traffic counts, axle load spectrum / vehicle damage factor for different categories of vehicles, periodic pavement condition in terms of roughness and different distresses, road geometric inventory, road structural inventory, history of maintenance activities carried out in the past alongwith with the costs and availability of funds.

With the advent of computer assisted information technology, the creation of a well structured database, retrieval of information and analysis of data have become flexible and easy. It is essential that data items are restricted to only those, which are absolutely required for the system and they need to be carefully examined as to how it is to be used and what information it will yield. The essential features of a data base are:

Referencing System

The most essential requirement of a road network database is a suitable referencing system for defining various sections in the network. The referencing system should be easily understood and capable of being linked easily to the road condition measurements at the time of survey. A suitable referencing system characterizes the road network into branches and sections based upon some sectioning criteria as described below.

Links - A link is a readily identifiable part of the road network and has a distinct function. The easiest way to identify the links comprising the road network is to use the existing name identification system used on the highway agency's road network maps. Alternatively, each link can also be identified, by assigning to it, an alphanumeric descriptive name called the 'link name' and an alphanumeric code called the 'link ID.' The link ID is a unique code that is used to help store and retrieve data from the database.

Sections - Because a link is typically a large unit of the road network, it does not always have consistent characteristics throughout its entire length and thereby does not require the same maintenance and rehabilitation (M&R) treatment, at the same time, throughout its entire length. Therefore, the links need to be divided into smaller components called sections for management purpose. A section may be considered as the smallest management unit while contemplating selection and application of the M&R measures. Each link shall comprise of at least one section but may consist of more if pavement characteristics vary throughout the link.

Criteria for Sectioning of Network – The pavement structure is one of the most important criteria for dividing a link into sections. The structural composition of pavement (layer thickness and materials) should be consistent throughout an entire section. The pavement structure can be verified by taking limited number of cores and then comparing with the available construction records. After each section has been initially inspected, pavement condition within the section could be used to subdivide it into other subsections, if a considerable variation in the condition exists. The agency must utilize its own judgement in deciding about sections, especially with respect to economics of implementation. If the sections are too short, it will require higher implementation effort and cost. On the other hand, if the sections are too large, the road characteristics may not be consistent throughout. Therefore, the sections may just be small enough to schedule individual M&R measures productively.

Database development for maintenance management system, involves following activities:

- Identification of data elements
- Classification and regrouping of data elements
- Preparation of data formats
- Data collection
- Computerisation of data

9.2. Identification of Data Elements

Identification of data elements is necessary for development of any database, so that advance planning is done to structure the data modules based on number of records, fields, etc. required for the element. Also, only useful data is collected as data collection is very expensive.

9.3. Classification and Regrouping of Data Elements

Classification and regrouping of data elements is necessary, as for the pavement maintenance management system some information is collected only once and some is collected on time series basis. Regrouping of data is also necessary for database development. For example traffic and axle load data shall not be mixed

with pavement condition data, though both types of data are time series data. The data base for pavement maintenance management system can, therefore, be broadly divided into the following categories and modules:

- One time data
  - Road inventory
  - Construction history
  - Crust details
  - Material properties
  - Maintenance strategies with unit cost

- Time series data
  - Traffic and axle load
  - Road condition
  - Deflection
  - Environment
  - Maintenance history

The various data elements of the database are given in Fig. 9.1.

9.4. Computerisation of Data

Computerisation of data involves the following steps :

- Compilation and coding of data
- Punching / feeding and verification
- Validation, error rectification and updation

9.4.1. Compilation and coding of data: Raw data collected from the field should be compiled properly before punching it into electromagnetic media. Data should be coded in the same format in which it is to be punched in the computer. It is necessary to bring the data into ready to feed in computer form and weed out the errors at the initial stage of data collection.

9.4.2. Punching and verification: Compiled data should be punched in computer carefully. It should also be verified after punching. This verification can be done by taking the print of the punched data or it can be read on the computer screen by other person. This verification will eliminate the errors which might have crept during the punching process.

9.4.3. Validation, error rectification and updation: Further validation of punched data is necessary to weed out the errors and illogical data crept during punching. To weed out illogical data and other mistakes, simple validation checks, such as, total distress and roughness values should be between 0-100 per cent and 1500-

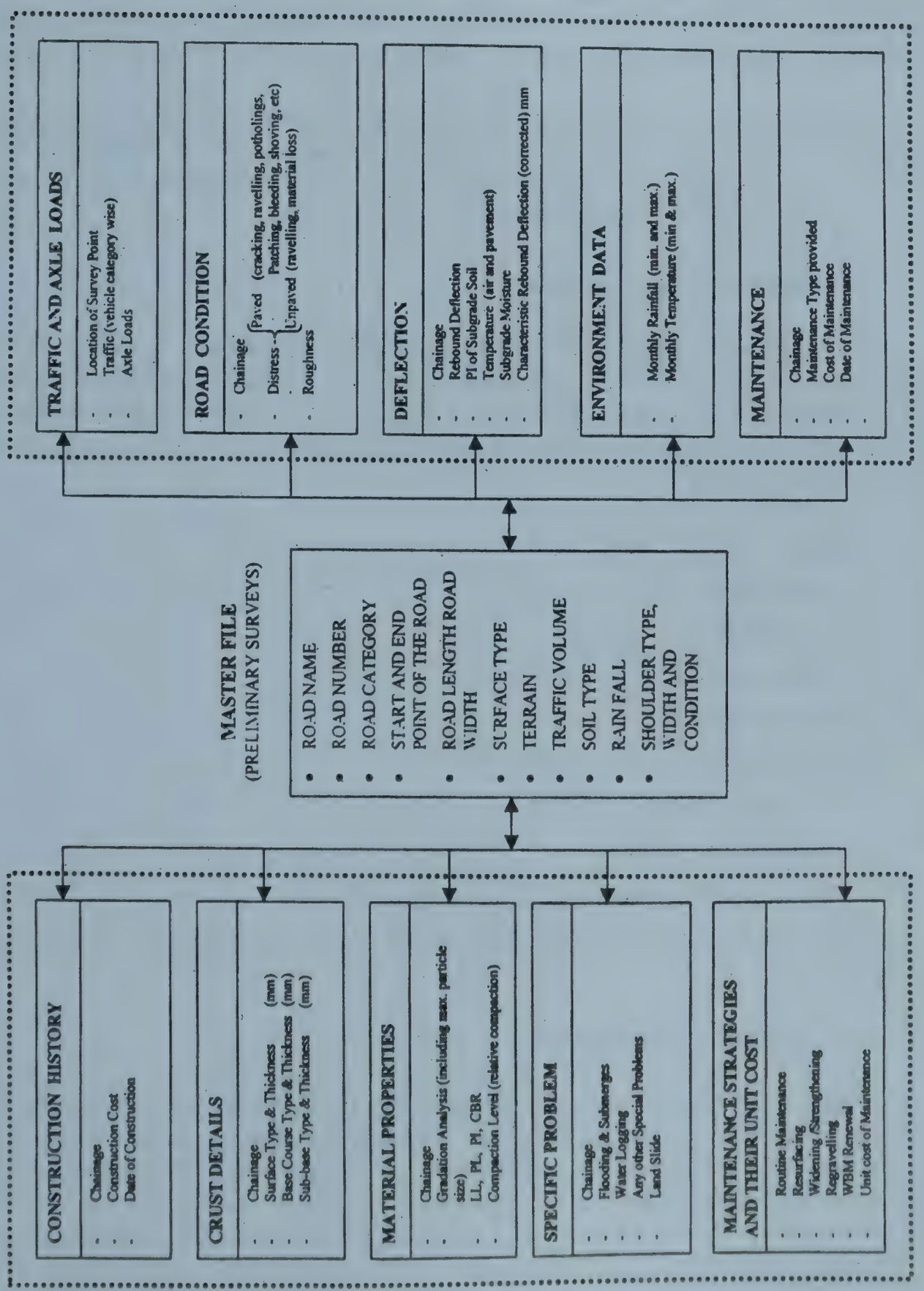


Fig. 9.1. Chart Showing Classification of Data

12000 mm/km respectively, can be applied to find out the errors in the data. Similarly, checks can be applied on axle loads, gross weight, the laden and unladen weight of the vehicle for not exceeding the specified limits / ranges. The errors flagged out by validation checks should be carefully looked into and updated in the data base.

The error free data obtained after applying all the above mentioned steps is the master data. For further use, another copy of the same can be made as a back-up file in the computer. The various steps involved in computerisation of data are presented in the flow chart given in Fig. 9.2.

9.5. Hardware Requirements

The hardware requirements for a pavement maintenance management system depend on the size of data requirement. Computer systems of many configurations are available in the market. However, a desktop with following specifications and peripherals can be used for the development of database and a pavement maintenance management system:

Pentium – III/IV with
1.6 MHz CPU,
40 Gb HDD
132 Mb RAM,
1.44 Mb FDD,
CD writer
17" colour monitor,
Deskjet colour printer
Scanner and Windows - X P operating system.

These specifications are suitable to load and run available tools and software packages.

9.6. Software Requirements

Many good database development software packages are available in the market, such as, MS-Access, Oracle, GIS, etc. GIS can be used for database development as it is good for the organisation of information and the design of information systems. The essential aspect of GIS is the concept of location as the basis for the structuring of information system. MS-office is preferred since it is equipped with MS-Excel and MS-Access which are good for database development. MS-Access is user friendly. Each file should have a common field so that at the time of extracting the information, the common field will link the information for a particular kilometer of a road from all the files/modules.

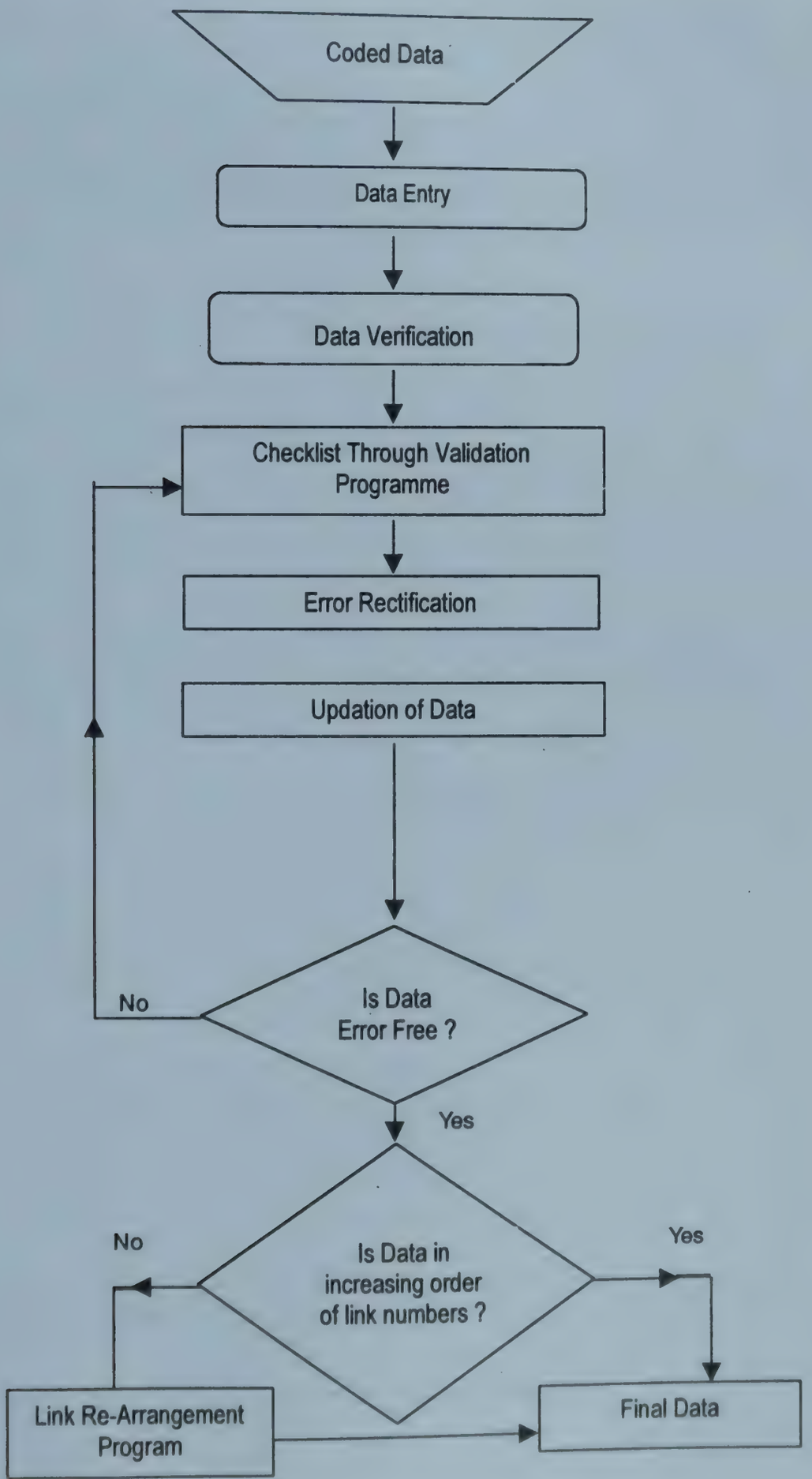


Fig. 9.2. Flow Chart for Computerisation of Data

In the data base, Road Name, Road Number, kilometer from – kilometer to is a common field in all the data files/modules. This common field will be the key for extracting the information from all the files/modules. MS-Excel is very useful for development of pavement maintenance management system. It will not only be useful for statistical analysis of data but will also help in calculations of "Internal Rate of Return" (IRR) and "Net Present Value" (NPV), which are the main basis for economic analysis/prioritization for different strategies.

10. DATA ANALYSIS

10.1. Analysis of Various Parameters

The data collected during field studies shall be analysed to obtain various parameters that are finally to be used in the development of a maintenance management system (MMS).

10.1.1. Inventory data: It consists of two types of data, viz.,

(i) Office data (basic inventory)
(ii) Field data (detailed inventory)

Office Data : This data consist of category of road, length, width, surface type, thickness of different layers, the historical data on original pavement, subsequent renewals information, pavement strength, age, etc.

Field Data : This data consist of curvature and gradient (rise/fall) per km length and is collected by making use of equipment, like, Gyroscope and Gradometer (discussed earlier in Section 7.2).

The horizontal profile of the road is measured with the help of Gyrocompass and is calculated using the formula given below :

$$R = \frac{360}{(D_1 - D_2)} \times \frac{(N_2 - N_1)}{2} \times 20$$

Where,

R = Radius in meters per kilometer
D_1 = Gyroscope reading at the beginning of the curve
D_2 = Gyroscope reading at the end of the curve
N_1 = Distance measuring counter reading at the beginning of the curve
N_2 = Distance measuring counter reading at the end of the curve

Similarly, gradient is measured by use of a Gradometer (vertical profilometer) in terms of rise/fall, and is calculated using the following formula :

$$\text{(Rise/Fall)} = \frac{20 \times \text{difference in counter readings}}{100}$$

$$= \frac{\text{Difference in counter readings}}{5} \text{ m/km.}$$

10.1.2. Pavement condition data: The data on distress collected from a detailed condition survey, as mentioned in Section 7.3, shall be analysed. The affected area for each mode of distress, viz., cracking, potholes, patching, bleeding, depression, edge breaking, ravelling, shoving, etc. is worked out as per cent of total area km.-wise. The area affected with ruts in each km should be marked and the rut depth (max) per km noted.

10.1.3. Roughness data: The roughness data collected from field, as mentioned in Section 7.4 shall be analysed for riding quality. The data on bumps and number of wheel revolutions give the roughness in mm/km or cm/km, as follows :

$$\text{UI (mm/km)} = \frac{\text{Bump Integrator reading* x No. of wheel revolutions/km}}{\text{No. of wheel revolutions recorded}}$$

* If it is in inches, it should be multiplied by 25.4 to convert into mm.

10.1.4. Strength data: This is represented in terms of deflection or modified structural number.

10.1.4.1. Deflection: If the existing pavement's structural adequacy is evaluated by deflection with benkelman beam, then the inadequacy in structural strength, if any, is indicated by the rebound deflection. The overlay requirement is worked out from the characteristic deflection, which is calculated as follows :

$$Dc = \overline{D} + t \times \sigma$$

where, $\overline{D}$ is mean rebound deflection of the road section, which is calculated using the rebound deflection values measured at all points after applying the needed temperature and moisture corrections, as per IRC : 81, σ is the standard deviation, and 't' is taken as 2 for primary roads and 1 for secondary and urban roads.

10.1.4.2. Structural Number (SN): The structural strength is also indicated by structural number and expressed as under:

$$SN = \sum_{i=1}^{n} a_i d_i$$

where d_i = Thickness of a layer, inches
a_i = Strength co-efficient of a layer

The strength co-efficients suggested for different pavement materials are given in Table 10.1.

Table 10.1. Strength Co-efficients

Layer/Specification	Strength Coefficient
Bituminous Concrete (BC) 40 mm	0.30
Bituminous Concrete (BC) 25 mm	0.28
Semi-Dense Bituminous Concrete (SDBC) 25 mm	0.25
Dense Bituminous Macadam (DBM)	0.28
Premix Carpet (PC) 20 mm (only in the case of overlaid pavements which have PMC as original surfacing)	0.18
Bituminous Macadam (BM)	0.18
Water Bound Macadam (WBM Gr. I, II or III)	0.14
Wet Mix Macadam / (Lime Cement) stabilised Granular Sub-Base (GSB)/Quarry Rubish (QR)/ Moorum	0.11

Source :

i) TRRL Laboratory Report 673, "The Kenya Road Transport Cost Study : Research on Road Deterioration", by J.W. Hodges, J.Rolt and T.E. Jones.

ii) "Road Deterioration and Maintenance Effects," Model for Planning and Management, A World Bank Publication, 1987, by William D. O. Paterson.

iii) "Pavement Performance Study – Study on Existing Pavement Sections", Vol.II, Central Road Research Institute, Sept. 94.

iv) "Pavement Performance Study – Study on New Pavement Sections", Phase-I, Central Road Research Institute, May 2000.

Modified Structural Number (MSN)

The strength of the subgrade also affects the pavement strength. Hence, the Structural Number as determined above is modified to take into account the subgrade affect, using the following formula, developed during Kenya study :

$$MSN = SN + 3.57 (\log CBR) - 0.85 (\log CBR)^2 - 1.43$$

where,
MSN = Modified Structural Number
SN = Structural Number
CBR = Subgrade Strength at Field Conditions

10.1.5. Traffic data: The classified traffic data collected from the field by a 3/7 days study, depending upon importance of road, as specified in para 7.9.1 earlier, is compiled to get the daily categorywise number of vehicles plying on the road, by averaging the data for the entire period. The main purpose is to know the number of commercial vehicles per day.

The category-wise composition of traffic may be suitably represented schematically, by using a 'Pie Diagram' or any other means, for better understanding.

10.1.6. Vehicle damaging factor: The data collected from axle load survey, as mentioned in para 7.8.1, shall be analysed as per the details given below to get the vehicle damage factor (VDF) :

The damaging effect of axle loads for different vehicle types, is worked out by the following formulae using "Fourth Power Law".

$$\text{Front Axle} = \left[\frac{\text{Axle load}}{6600}\right]^4$$

$$\text{Single Axle dual wheel assembly} = \left[\frac{\text{Axle load}}{8160}\right]^4$$

$$\text{Tandem Axle} = \left[\frac{\text{Load on Tandem Axle}}{15100}\right]^4$$

The summation of damaging effects of all vehicles will give the total damaging effect of the vehicles weighed.

The vehicle damage factor for the road is then computed as follows:

$$\text{VDF} = \frac{\text{Total damaging effect}}{\text{No. of commercial vehicles weighed}}$$

10.2. Pavement Deterioration Models: Pavement deterioration models are imperative for development of a pavement maintenance management system. These models play a crucial role on several aspects of the M&R strategies, including financial planning and budgeting, pavement design and life cycle economic analysis. The purpose of the performance models is to predict the future condition of a given pavement. Such a prediction is necessary to estimate the timing of major maintenance, predict performance after major maintenance and to relate, the user costs to pavement performance.

10.2.1. Use of pavement deterioration models in PMMS: The pavement deterioration models have several uses in PMMS, such as :

(i) to analyze the conditions and determine the maintenance and rehabilitation requirements
(ii) to decide the useful service life of the pavement on the basis of reduction in performance value to a certain terminal value
(iii) to estimate long range funding requirements to preserve the pavements
(iv) to provide major inputs to perform life cycle cost analysis to compare the economics of various M&R alternatives
(v) to study the effects of various budget levels on future pavement condition

10.2.2. Applicability of available models: Models developed under Pavement Performance Study – Study on Existing Pavement Sections (PPS-EPS), are the only Indian tools available for pavement performance prediction under local conditions. These can be conveniently used for planning of maintenance strategies. The models are incremental in nature and yield yearly predictions to make inputs in planning maintenance activities.

These models are developed as a function of current pavement condition, pavement strength, time interval, incremental traffic volume and loading, maintenance inputs and construction quality. The progression of cracking, ravelling and potholes and the progression of roughness can be predicted using these models. However, these models were developed for surfaces, like, BC, SDBC and PC only and for conditions prevailing in Uttar Pradesh, Rajasthan, Haryana and Gujarat States.

In the absence of any such tools for the use in MMS, the most generally used tool, thus, for HDM-III, the latest version of which HDM-4 is also available now. These need to be calibrated and adopted for local conditions.

11. ORGANISATIONAL REQUIREMENTS

11.1. General: The road network in the country is constructed and maintained by various Government agencies/local bodies. It is, therefore, essential to involve the agency's unit identified for database development, in developing a specific maintenance management system (MMS) and putting it into operation to get the best results. With the decentralisation policy, the responsibility of development and maintenance of different categories of roads is vested with different organisations. For primary roads, the nodal agency to identify the priorities and initiate action related to maintenance implementation is either MoRT&H or NHAI. In the case of secondary and tertiary roads the maintenance is taken care by State Government while for the urban roads it is looked after by the local bodies.

11.2. Institutional Arrangements for Implementing MMS

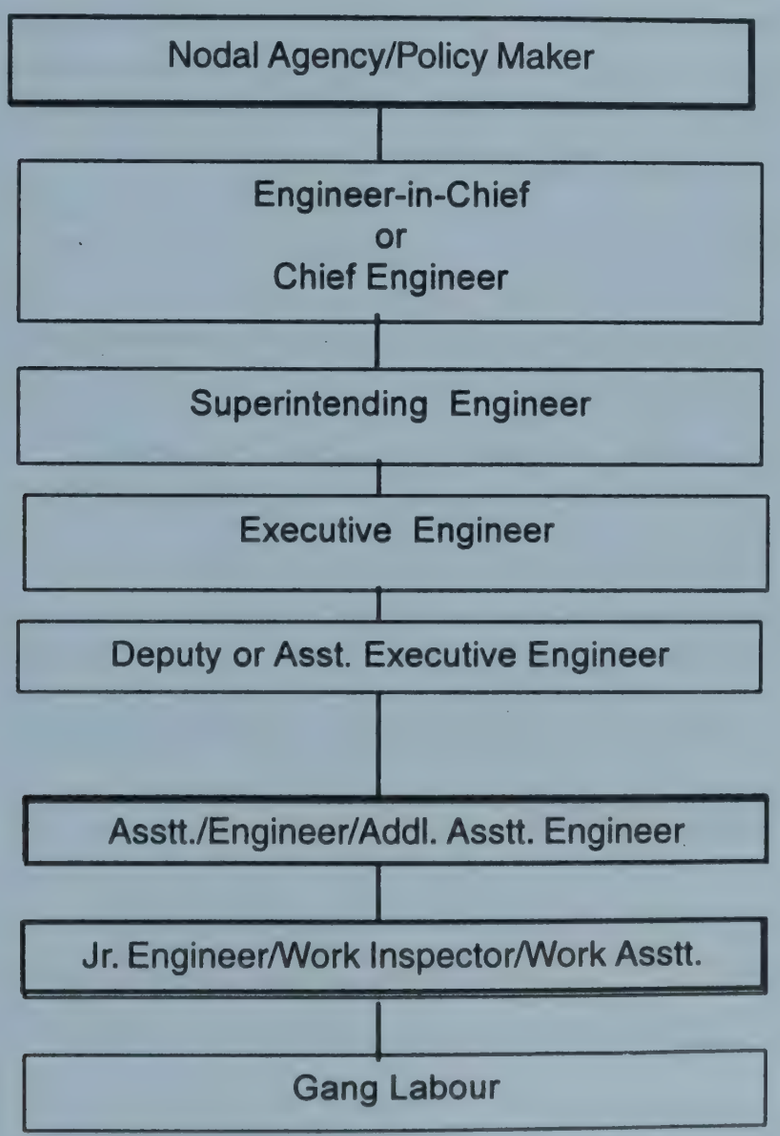
The best laid plans for a maintenance management system are useless until these are put into practice or properly implemented. Implementation of any MMS may vary for different situations and agency to agency depending on their needs and resources available. However, several major steps in implementing any MMS are identified as given below:

1) decision for implementation of a pavement management system, or implementation of improvements to an existing system
2) formation of a steering committee to identify needs, develop basic scope and agenda for the system and monitor implementation
3) review of existing organisation, database, methods and procedures within a defined pavement management system framework
4) development of an implementation plan with recommendations and schedule
5) actual work activities for each implementation stage of the MMS, including plan and schedule updates, documentation, training and software installation
6) monitoring the system and periodic improvements

A decision for implementation is the first major step in MMS either at network or project level. Good communication and recognition of organisational issues determines to a large extent, the success of the system. In order that a maintenance management system is successfully implemented, it is important to know the actual functioning of organisation, which is normally not well represented by the usual flow charts of the administrative structure. Hence, the review of organisational requirements shall first take stock of the nature of organisation itself (administrative structure and responsibilities, communication flows and maintenance work programmes). Then it should define building block based framework. It should further review the existing data bases, construction and maintenance methods and procedures, resources, etc., within the framework of the building block based system.

Organisational issues are an integral part of the activities and functions of any agency. Since human aptitude opinions and biases are a major and essential part of any decision making process, institutional issues are bound to affect the implementation of any new methodology or technology within an organisation.

A general hierarchial, organisational setup existing in the country is represented as follows :



While the Chief Engineer has the overall responsibility of maintenance of a particular road category in a State, the Superintending Engineer heads a circle, controlling normally 3-4 districts. The Executive Engineer looks after each district by the support of 3-4 Deputy Executive Engineers or Asstt. Executive Engineers managing their respective Sub-Divisions. The Sub-Divisions, in turn, have Asstt. Engineers, holding charge of a certain section to whom Junior Engineers report. The actual field work at grass root level is carried out by JEs and work inspectors with the assistance of Road Karkun or Work Assistants and the gang labour.

In the present set-up for implementation of maintenance work, mainly the ordinary repairs, are carried out departmentally using gang labour/task force available on a permanent basis. Normally, an Executive Engineer looks after 1000-2000 km of roads while a Deputy Executive Engineer is incharge of about 500 km of roads. The AE and JE are expected to take care of 150-200 km and 60-100 km of roads, respectively. But, in majority of the States, these officers are not exclusively available for road works since the building works and other activities are also part of their duties.

11.2.1. Duties/responsibilities of field personnel: The field personnel are directly responsible for implementation of the maintenance related activities including implementation of a specific MMS. Some of the well defined and duly established duties are given below:

Executive Engineer

- Planning and finalisation of maintenance measures based on survey reports
- Arranging men, materials and machinery in advance as per requirements
- Finalising actions on reports of Asstt. Engineers
- Co-ordination with various agencies, like, local administration, traffic police, publicity media, etc., as and when required
- Reviewing regularly the activities, results, reports and make changes, as required
- Initiate steps for finalizing permanent restoration works

Assistant Executive Engineers

- Planning and arranging for the required surveys
- Getting estimates prepared, checked and submited
- Reporting about needs and measures, to higher authorities for necessary action
- Carry out action on the report of subordinate engineers
- Supervise the field arrangements including safety measures for workmen

Assistant Engineers/Junior Engineers

- Preparing estimates for maintenance actions after carrying out condition surveys
- Reporting observations to higher authorities
- Arranging for clearance at site
- Manoeuvre field activities with the assistance of lower staff

11.2.2. Corridor management: Under the 'National Highway Development Project' (NHDP), a length of 13,252 km of National Highways is being developed on main corridors. The development of roads under NHDP is with the National Highway Authority of India (NHAI). Being important corridors, the maintenance requirements of these roads are of higher standards. Therefore, the MMS shall be structured and implemented to provide the best possible serviceability level on these roads.

The main features of these corridors include divided carriageways, service roads, grade separators, underpasses and enhanced safety features. Hence, the maintenance aspects should address proper upkeep of not only carriageways but also of service roads, approaches and allied structures. The database and the maintenance management system should be comprehensive to take care of the defined serviceability requirements. For effective implementation of the maintenance programmes, the nodal agency should have engineers exclusively identified for the purpose. For each corridor, an officer not below the rank of General Manager should be directly made responsible to take care of all the matters concerned with maintenance and its management. To assist him in implementation of the programmes, he can be assisted by other officers, i.e., Deputy General Managers and Assistant Managers to take care of appropriate corridor lengths.

11.3. Shortfalls of the Present set-up/Structure

The present organisational structure and the mechanism adopted for maintenance has not been very effective. Though various codes/guidelines are available from IRC/ MoRT&H for implementing the maintenance measures scientifically, supported by engineering approach for evaluation of road condition, this is lacking in the actual practice. The required condition surveys of roads are many a times not carried out by the concerned engineers. There is hardly any timely action taken for treatment of cracks, filling of potholes and depressions, etc. The preparation of maintenance programmes and scheduling is far short of requirements, with almost the total absence of quality audit approach.

The different organisations/officers responsible for maintenance activities are entrusted with other works also. The absence of adequate funds for maintenance has added to the problems of the engineers. Many times, the available equipment and machinery are not maintained properly. Even when the machinery and facilities are available, lack of appropriate knowledge and techniques because of untrained crew, do not yield desired results. Further, the inter-disciplinary transfers of engineering staff do not enable them acquiring indepth knowledge.

The major institutional factors identified for non-effective implementation of MMS by agencies are classified is two categories, viz., immediate and long term.

(i) Immediate factors
- Limited availability of technical and financial resources to implement MMS without unacceptable disruptions to daily traffic
- Limited availability of fiscal resources and technical knowhow to support the MMS once implemented

(ii) Long term factors
- Fiscal and technical inability to continually access and incorporate rapidly improving technology
- Lack of a clear organisational philosophy

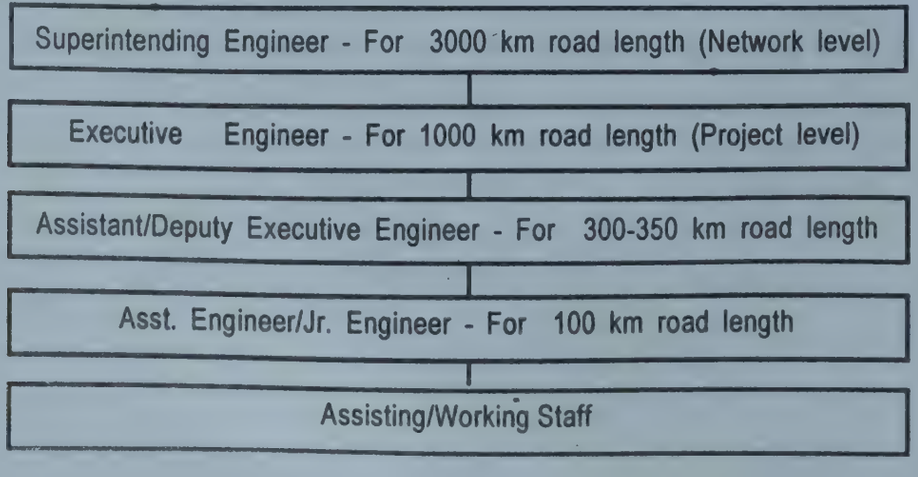
11.4. Suggested Changes

The present organisational structure and the mechanism for execution of routine maintenance works by engaging casual labour/road gang needs to be modified. Since proper equipment and machinery are not available, the output does not match with the expenditure involved and in addition leads to poor quality works.

The margin between the maintenance grants and capital outlays is very thin and delicate. Roads not being attended for timely maintenance inputs deteriorate fast and maintenance nature of works get transferred to capital outlays, such as, a strengthening work. A proper allocation and, if required, augmentation of maintenance grants by additional taxing may be required. While planning a maintenance work the actual needs should be assessed scientifically. Wherever required, the profile correction and depression filling shall be provided in the estimate, executed and then only the structural deficiencies need are taken care in the form of overlays.

An exclusive 'Maintenance Management System Implementation Unit' shall be identified within any Organisation responsible for maintenance of roads at network level or project level. A Superintending Engineer shall be given the overall co-ordination responsibility at network level, while an Executive Engineer shall do the same at project level.

The suggested set-up is shown below:


Superintending Engineer - For 3000 km road length (Network level)
Executive Engineer - For 1000 km road length (Project level)
Assistant/Deputy Executive Engineer - For 300-350 km road length
Asst. Engineer/Jr. Engineer - For 100 km road length
Assisting/Working Staff

11.5. Maintenance by Contract

The approach of privatising the construction and maintenance activities of roads has been gathering interest of late. The inefficient, inadequate and poor quality maintenance of roads yields no useful results towards improvement of rideability and extension in pavements useful life. To have a more dedicated approach and to provide the user with good quality roads the maintenance by departmental agencies needs to be changed over to a contract system, gradually, as viable.

Achieving better outputs by contracting, is slated through better planning. A number of roads of the same condition may be grouped in an area or block, to make it a financially attractive offer. Based on the data collected as inputs to the MMS developed for the purpose, the appropriate maintenance measures are identified. A detailed list of various maintenance alternatives for different groups of roads, the detailed specifications to be adopted, the required periodicity, the machinery, manpower requirement, etc. are indicated. The clauses for quality work and termination for unsatisfactory works shall be mentioned. Accountability in the form of performance guarantee, penalty clauses and alternate mechanism for non-performance or non-compatibility shall also be stipulated.

Giving impetus to contracting entrepreneurs for an active role in maintenance related activities can bring in beneficial changes in the existing monotonous approach. The contracting mechanism based on fixed time fixed price basis with penalty for delays, will help to catalyse the works for speedy completion. This will result in considerable saving in road user's time and costs. Opening to a competitive atmosphere, with a number of contracting agencies entering the fray can deliver better quality roads. The making of user-friendly and eco-friendly roads will benefit both the investor and country's economy. The private entrepreneurs or contractors can give complete range of effective services, such like, road maintenance and bridge maintenance, etc. from the same organization. The contracting concept will put an end to the slow progress and poor quality resulting from the present system and the hierarchical hindrance within and will ultimately eliminate the losses in economy.

11.6. Training

The present system of maintenance by subjective decisions needs to be changed and redefined. Proper data collection on pavement condition and needs for upkeep, using automated equipment, scientific tools for analysis, and a properly developed 'Maintenance Management System (MMS)' are necessary for all the maintenance related activities. The proper training of the staff involved in various aspects, such as, data collection, use of equipment, database development and operationalisation of MMS are essential. Use of new products, specifications and techniques in the maintenance, like, the cold mix technology shall get proper attention of all those involved. The practice of compromising on the performance quality, for any reason whatsoever,

shall be discouraged. Attempts should be made from top to develop scientific temper among their sub-ordinates. Training is necessary at all levels though the aspects needing training may vary with the level of the staff. The training and retraining shall be made a continuous process of any department.

11.7. Quality Audit in Maintenance Activities

A 'Quality Audit' is an independent and systematic review/evaluation to determine the extent of compliance of quality measures and results with planned arrangements. It is a check to see that these arrangements are proper and effectively implemented to meet the objectives, the quality audit done by any party other-than those who are directly identified with the administrative or implementing set up, is referred to as 'third party audit'. This has the benefit of providing an independent and unbiased review. Such audits are expected to ensure the conformity of set plans to specifications, procedures and end results. Quality audits in maintenance schedules help ensuring anticipated performance results. Major maintenance activities when subjected to quality audits help in optimal realisation of money spent and enhanced life of pavement at reduced costs.

12. INTERVENTION CRITERIA FOR MAINTENANCE PLANNING

12.1. General

The main objective of a pavement maintenance management system is to provide a scientific tool to maintain roads at desired serviceability levels. It is also well accepted fact that due to paucity of funds it is not possible to provide the highest level of serviceability. Also, in some areas the low volume of traffic do not justify high levels of serviceability. Since the pavements deteriorate with time, it is necessary to maintain/ rehabilitate them to provide minimum desired service to its user and save the valuable assets.

The maintenance inputs depend on :

1. structural condition of the original pavement, which can be measured in terms of rebound deflection
2. surface characteristics of the original pavement, such as, unevenness and distress (cracking, potholes, rutting, ravelling, etc.)
3. road maintenance policy and practices
4. drainage and other local conditions
5. traffic intensity, its distribution over the carriageway, and the load in terms of cumulative standard axles on the pavement during the period of consideration, climate and other environmental factors.

There are two types of maintenance inputs in practice, viz.,

- time bound (scheduled) maintenance, and
- pavement condition responsive maintenance

12.1.1. Time bound (scheduled) maintenance: The present policy of maintenance of roads is based on providing routine maintenance whenever required and renewal/ strengthening after every five years without analysing its economic implications. The main drawback of this policy is that some roads, though good, are resurfaced as per time specific renewal cycle, while some other roads deteriorate quickly, eventhough needing renewal but not covered by the maintenance cycle.

12.1.2. Pavement condition responsive maintenance: Pavement condition responsive maintenance is very useful for judicious disbursement of maintenance funds. Most recently developed maintenance tools/software packages, such as, HDM-4, though have provision for time bound maintenance intervention criteria, but prefer for condition responsive maintenance intervention.

For the Indian conditions, it is suggested that condition responsive maintenance intervention criteria may be adopted. To formulate condition responsive maintenance criteria some basic minimum desired serviceability level need to be fixed. The suggested criteria is based on the widely accepted performance indicators, such as, roughness, cracks, rutting, skid, potholes, etc.

12.2. Intervention Criteria

Considering the above performance indicators, the suggested intervention criteria for primary, secondary and urban roads are given below :

12.2.1. Primary roads: It is not possible to maintain all the primary road network to the highest level-of-service due to constraints of funds or otherwise. Accordingly, the maintenance programme shall be divided into three levels, which are identified as level 1, 2 and 3.

- Level 1 is the desired level that provides for highest level of comfort, convenience and safety.
- Level 2 is the one to which the road deteriorates from level 1 after two-three years of use before fresh maintenance is implemented.
- Level 3 represents the minimum level necessary to protect the investment and provide reasonable level of safety.

Table 12.1 shows the suggested intervention levels for primary roads.

Table 12.1. Intervention Levels for Primary Roads

S. No.	Serviceability Indicator	Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1.	Roughness by Bump Integrator (max. permissible)	2000 mm/km	3000 mm/km	4000 mm/km
2.	Potholes per km (max. numbers)	Nil	2-3	4-8
3.	Cracking and patching area (max. permissible)	5 per cent	10 per cent	10-15 per cent
4.	Rutting (20 mm maximum permissible)	5 mm	5-10 mm	10-20 mm
5.	Skid resistance (Skid number minimum desirable)	50 SN	40 SN	35 SN

12.2.2. Secondary roads: It is quite obvious that the secondary roads consisting of State Highways and MDRs can not be expected to be maintained upto the serviceability level of primary road network, since they attract relatively lesser attention and funds. Also, the functional and operational requirements do not justify the maintenance of

these roads with those of primary roads. Hence, while the intervention level 1 and level 2 for secondary roads are being considered as level 2 and level 3 of primary roads, values for level 3 indicated are based on similar extended pattern of values of primary roads. The suggested intervention levels for secondary roads are given in Table 12.2.

Table 12.2. Intervention Levels for Secondary Roads

S. No.	Serviceability Indicator	Level 1	Level 2	Level 3
1.	Roughness by Bump Integrator (max. permissible)	3000 mm/km	4000 mm/km	5000 mm/km
2.	Potholes per km (max. numbers)	2-3	4-8	9-12
3.	Cracking and patching area (max. permissible)	10 per cent	10-15 per cent	Upto 25 per cent
4.	Rutting (20 mm maximum permissible)	5-10 mm	10-20 mm	Upto 20 mm
5.	Skid resistance (Skid number minimum desirable)	40 SN	35 SN	30 SN

12.2.3. Urban roads: The urban roads can be classified into different categories as follows:

1) Category I : primary corridors consisting of arterial roads
2) Category II : secondary corridors consisting of sub-arterial roads
3) Category III : secondary corridors consisting of other roads

Since the road pavements in urban areas have different levels of structural and functional inadequacies, it is not a simple task to predict their rate of deterioration before or after laying the overlays. The first stage improvement include mainly, improvements of drainage system and sidewalks, relocation of water supply and sewerage pipes and provision of service-line facilities on both sides of road to prevent cross cutting of pavement in future. Though, the cost involved for the proposed first stage improvements of roads may be enormous, it is essential to make an one time investment by which several unpredictable damages and untimely pavement failures could be avoided. The following measures are considered essential, where ever possible, during the first stage maintenance and overall improvement for the road pavements in urban areas:

i) To improve the drainage system by providing additional transverse drains and by improving the existing drainage system, as suggested.
ii) To shift the main water supply and sewerage pipe-lines located under the carriageway to one side of the road at least on primary road system with heavy bus traffic to prevent localized pavement failures due to leakage of water.

iii) To provide the service lines, such as, water supply, drainage, electricity and telephone conduit pipes from one side and the road to the establishments on the other side by providing the cross service lines at the pre-determined intervals before the first stage strengthening. The trenches of specified size are to be cut open across the existing roads at specified intervals and the cross service pipe lines may be connected to the four longitudinal service mains and appropriate junction points (pipe joints/manholes/junctions boxes for water supply, sewerage, electricity and telephone lines) may be provided on the other side of the roads. These trenches should be properly filled up and the cross cuttings of the pavements should be built-up before providing the overlay.

iv) To make profile corrections of the existing pavements by (a) filling-up the large depressions and ruts, (b) correcting the cross slope, i.e., camber on straight road stretches and super-elevation on horizontal curves.

v) Strengthening structurally inadequate pavements by overlays of appropriate composition and thickness.

vi) Resurfacing the functionally inadequate pavements to upgrade the surface condition to a minimum acceptable level of Unevenness Index.

vii) When the above works are completed including the construction of pavement overlays of appropriate thickness, the levels of the existing sidewalks, side drains and transverse drains may need to be changed in various stretches. Otherwise, the sidewalks are likely to be at a lower level than the pavement edge at some locations and the depth of longitudinal drains at pavement edges would exceed the permissible values on urban roads. Thus, there is a need to identify the locations and extent of raising the levels of the sidewalks and drainage system, it is considered desirable to provide a reasonably good paved surface for the sidewalks, by dressing and re-setting the existing stone slabs.

The suggested intervention levels for urban roads given below, in Table 12.3.

Table 12.3. Intervention Levels for Urban Roads

S. No.	Serviceability Indicator	Arterial Roads	Sub-Arterial Roads	Other Roads
1.	Deflection	1.0 mm	1-1.5 mm	1.5-2.0 mm
2.	Roughness by bump integrator (max. permissible)	2000 mm/km	3000 mm/km	4000 mm/km
3.	Potholes/km (max. numbers of size <100 sq.cm. and depth < 2.5 cm)	Nil	2-3	4-8
4.	Cracking and patch repairs (max. permissible)	5 per cent	10 per cent	10-15 per cent
5.	Rutting (max. permissible)	5 mm	5-10 mm	10-20 mm
6.	Skid Resistance (Skid number by ASTM-274) minimum desirable	50 SN	40 SN	35 SN
7.	User information	All road signs, road marking in good condition	Major road signs, road markings in good condition	Major road signs and markings in fair condition

13. MAINTENANCE STRATEGIES

13.1. General

The function of maintenance is to preserve the pavement in a traffic-worthy condition and to allow the movement of traffic at a requisite speed and safety. The maintenance strategies are based on assessment of needs with regard to the structural strength, condition and unevenness of surface and drainage. The main objective of maintenance management system is to provide an appropriate and economically viable maintenance strategy.

13.2. Evolvement of Maintenance Strategies and Techniques for Optimisation

The evolvement of maintenance strategy for any roadwork requires a thorough examination of a wide range of options, involving the initial standards of pavement, roadway features, the terminal standards for subsequent routine and periodic maintenance and pavement strengthening. The investigations on the structural strength of the pavements, along with the traffic details, will indicate the structural and functional deficiencies. This forms the basis for the determination of appropriate maintenance strategies. The pavements which are structurally adequate but functionally deficient, may require resurfacing or thin overlays. The pavements, which are structurally inadequate and functionally satisfactory, may need to be provided a thick overlay, keeping in view the traffic requirements. Pavements that are deficient both structurally and functionally will require rehabilitation/reconstruction.

The initial strengthening/resurfacing of pavements shall be decided to meet the minimum needs of both structural and serviceability conditions. The overlay thickness to meet the structural inadequacy can be decided using the Benkelman beam deflection values and the cumulative number of standard axles to be carried over the design life, as per details given in IRC:81-1997. The type of material to be used in overlay construction will depend on several factors, such as, importance of roads, design traffic, thickness condition and type of existing bituminous surfacing, construction convenience and relative economics. Before putting the overlay, the existing pavement surface shall be corrected and brought to proper profile by filling the cracks, potholes, ruts and undulations. No part of the overlay thickness shall be used for correcting the surface irregularities.

13.3. Optimum Maintenance Strategy

The optimum maintenance strategy for a project is decided based on the steps given below:

(i) A set of feasible maintenance strategies is selected.

(ii) Pavement condition is predicted for each feasible maintenance strategy within the analysis period.

(iii) Economic analysis is conducted for each alternative maintenance strategy.

(iv) The various alternative maintenance strategies are then ranked according to decreasing benefit/cost ratio and decreasing costs, discarding alternatives with lower benefit/cost ratio but higher costs.

(v) The alternative drawing the largest benefit-cost ratio gets precedence over the cheapest one.

13.4. Types of Maintenance

There are two types of maintenance, namely

- Routine maintenance (to cover ordinary repair)
- Major maintenance (to cover periodic renewals and rehabilitation)

13.4.1. Routine maintenance (preventive): Routine maintenance is necessary to keep the road at a minimum usable condition and covers the following:

- Crack sealing
- Pothole repair
- Reshaping
- Shoulder make-up

13.4.2. Major maintenance (corrective): It is necessary to keep the pavement structurally and functionally sound to serve the intended purpose. This category of maintenance involves good investment in terms of material and manpower costs. The main strategies are as follows :

- surface treatment/renewal
- overlaying/strengthening

13.4.2.1. Surface treatment: It is generally provided to meet the functional requirement of the carriageway for the riding comfort and safety of the user. Suggested resurfacing specifications are as follows :

i) 20 mm Premix carpet
ii) 25 mm Mix seal surface
iii) 25 mm Semi-dense bituminous carpet
iv) 25 mm Bituminous concrete

The specification mentioned at (i) is not to be considered for primary network.

13.4.2.2. Strengthening/riding quality improvement: It is provided to meet both functional and structural requirement of the road. Overlay/strengthening of the

pavement can be done by the following or any other specifications:

i) 20 PC + 50 BM
ii) 20 PC + 75 BM
iii) 25 SDBC + 50 DBM
iv) 25 SDBC + 75 DBM
v) 25 BC + 50 DBM
vi) 40 BC + 50 to 100 DBM

Specifications i) and ii) are not to be considered for primary road network.

13.5. Optimization and Prioritization of Maintenance Strategies

13.5.1 Total transportation costs : When planning investments in the road sector, it is necessary to evaluate all costs associated with the proposed project. These include construction costs, maintenance and rehabilitation costs, road user costs, and all other external or exogenous costs or benefits that can be directly attributed to the road project. The costs of construction, routine and periodic maintenance are usually borne by the agency incharge of the road network. However, road user costs are borne by the community at large in the form of vehicle operating costs (VOC), travel time costs, accident costs and other indirect costs. The primary function of a road investment appraisal model is, therefore, to calculate the cost of road construction, road maintenance and road user costs for a specified analysis period. These three costs constitute what is commonly referred to as the total (road) transport cost or the life cycle cost.

13.5.1.1. Road maintenance costs: The annual cost of maintenance is calculated from the routine maintenance, periodic maintenance, and any road improvements applied in a given year. These depend on the predicted pavement condition and the specified maintenance or improvement standard, which may include a combination of one or more different types of road works.

13.5.1.2 Road user costs: Road user costs may be defined as the costs incurred by the vehicle operators and by the travelling public at large. The three types of road user costs usually considered are associated with vehicle operation, travel time, and accidents.

Vehicle operating costs : These can be calculated from the sum of the vehicle resource components, including :

- fuel and lubricating oil
- tyres and spare parts

- vehicle maintenance labour costs
- vehicle crew wages
- vehicle depreciation and interest on capital

Travel time costs : These costs can be calculated from average vehicle speeds, travel distances and the unit costs per hour of road user's time. The average vehicle speeds are a function of road roughness, road width, and the vertical and horizontal alignment of the road.

13.5.1.3. Other exogenous costs and benefits: Other costs or benefits that can be directly associated with a road project may also be included in the economic analysis. These usually include independently assessed benefits accruing from socio-economic developments, such as, increased agricultural productivity, industrial output, accessibility benefits, etc. Exogenous costs could include the costs of providing diversion routes, noise barriers, and other impediments during construction.

13.5.2. Economic analysis: Economic analysis or life-cycle cost analysis of pavements is a tool used for economic assessment of competitive strengthening or maintenance strategies, and in the selection of most cost effective maintenance alternative. A detailed economic analysis of pavement maintenance strategies needs to be carried out for the optimum utilization of the resources. This may also be used in determining the optimum budget, i.e., the budget that will result in the highest rate of return on the investments made in maintaining the road network. In the economic analysis, maintenance and rehabilitation costs and road user costs are calculated for every alternative maintenance strategy.

In view of scarce resources, the economic analysis of maintenance proposals is essential. The main input parameters/tools required for economic analysis are given below:

- pavement geometry
- pavement structural strength in terms of deflection/MSN
- pavement condition
- traffic and axle loading (VDF) structural number and condition with annual traffic growth
- pavement deterioration prediction models
- maintenance strategies/alternatives with unit cost
- pavement condition improvement relationships for different maintenance prediction models
- vehicle operating cost models

13.5.2.1. Pavement geometry: This information on pavement width, rise plus fall, and horizontal curvature is necessary for calculation of vehicle operating cost (VOC).

13.5.2.2. Pavement structural strength: This information in terms of deflection or modified structural number is necessary for predicting future condition of the pavement.

13.5.2.3. Pavement condition: Present pavement condition is used as an input in pavement deterioration models for predicting future condition of the pavement.

13.5.2.4. Traffic and axle loading with traffic growth factor: Category wise traffic volume and growth factor, along with axle load spectrum of commercial vehicles, are important input parameters for this analysis. Traffic category with its growth is necessary for calculation of total vehicle operating cost. Traffic volume of commercial vehicles with axle loading is used to calculate vehicle damage factor (VDF) and subsequently commutative standard axles, an important input for pavement deterioration models.

13.5.2.5. Pavement deterioration models: In a major study, 'Pavement Performance Study-Study on Existing Pavement Sections' an exhaustive attempt is made to develop pavement deterioration models for Indian conditions. The details of the models are already given in Section 4.2.1 (iii). The study parameters include pavement state (original/overlaid), traffic intensity, climate, surface condition, age and the maintenance inputs. With the aid of a extensive database and analysis models were developed. The relationships developed under the study give deterioration trends for some types of surfaces. The resulted year-wise roughness is an important input parameter for calculation of vehicle operating cost.

In HDM-4 study also, deterioration models are developed for some surface materials. Here also, the year-wise roughness is the input parameter for calculation of VOC and cost calculations.

13.5.2.6. Roughness improvement relationships: Roughness improvement relationships developed under PPS-EPS study provides roughness values for PC, BC and Mix Seal Surfacing (MSS) after renewal or strengthening. The findings of Pavement Performance Study – Studies on New Pavement Sections and Existing Pavement Sections have suggested the following attainable roughness values after renewal/ strengthening :

PC	:	2500 mm/km
MSS	:	2400 mm/km
SDBC	:	2200 mm/km
BC	:	1800 mm/km

This roughness is used to calculate VOC after applying a specific maintenance strategy.

13.5.2.7. Maintenance strategies/alternatives: After prediction of pavement condition in terms of roughness, different maintenance strategies are applied for the intervention levels. Roughness of pavement will be reduced after application of maintenance strategy. Unit cost of maintenance, i.e., maintenance cost per lane per kilometer, in conjunction with vehicle operating cost, will be used for comparison of two maintenance alternatives.

13.5.2.8. Vehicle operating cost: Vehicle operating cost is an important element for economic analysis of maintenance. Calculate the vehicle operating cost for each type of vehicle for predicted roughness under "do nothing strategy" and one of the alternate applied for maintenance. This process is repeated for other maintenance applied. The vehicle operating cost for complete traffic is calculated year-wise. Flow chart for calculation of vehicle operating cost is given in Fig. 13.1.

13.6. Techniques of economic analysis: The main objective of economic analysis is to optimise the maintenance strategies. Optimisation is a method of setting priorities for maintenance expenditures, when there are budget constraints. Flow chart for economic analysis is given in Fig. 13.2. The following methods are used for optimising the maintenance strategy:

- net present value
- internal rate of return
- benefit - cost analysis

All these methods are based on discounting techniques as explained below :

It is necessary to discount the transport costs in each year of the analysis period to their value in the base year. This is carried out to reflect the time value of money represented by the opportunity cost in a given year by the discount factor for that year. Discount factors are derived from the equation below :

$$D.F. = \frac{1}{(1+r)^n}$$

where,

DF = Discount factor
r = discount rate in per cent
n = number of years from the base year

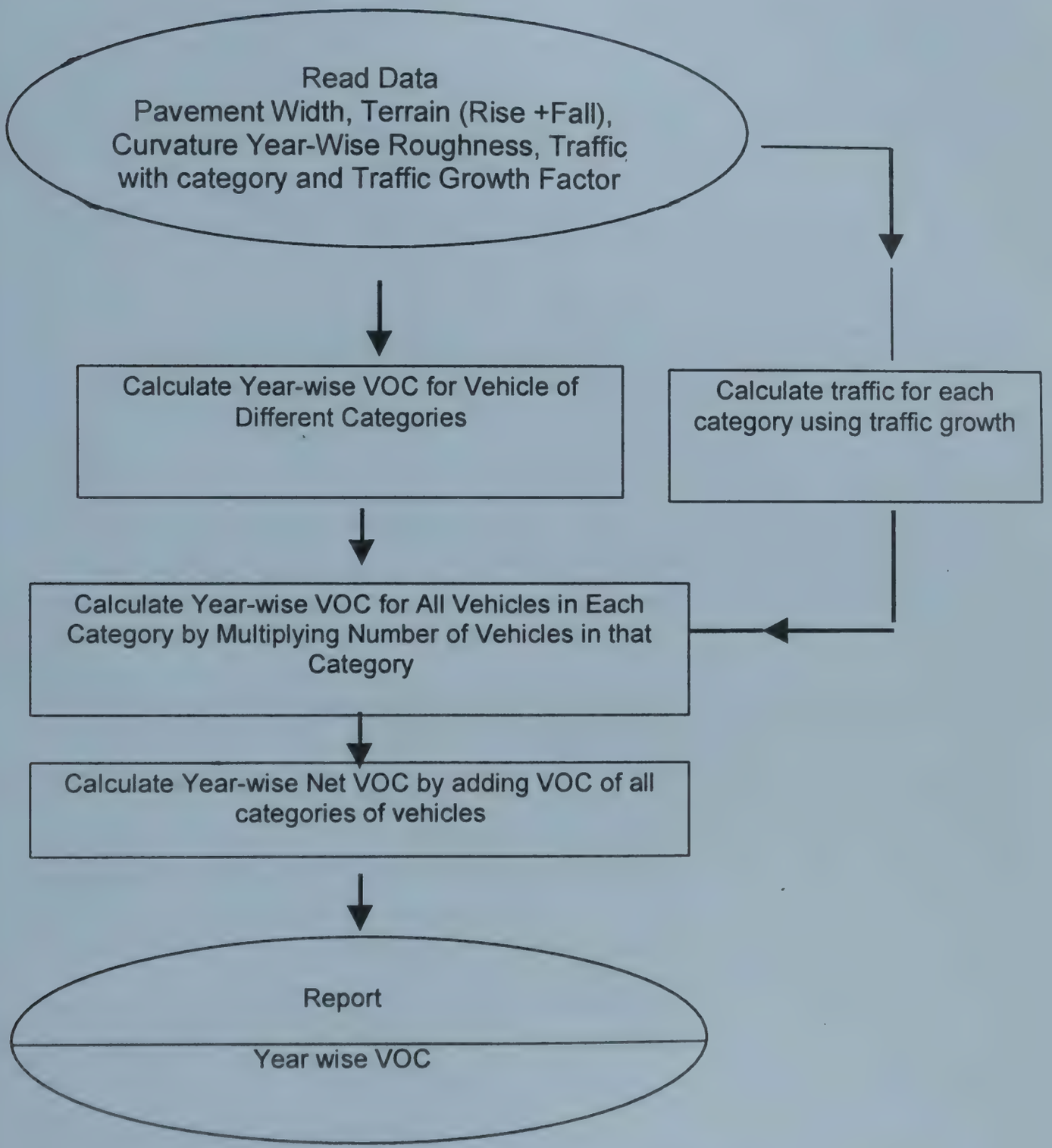

Read Data
Pavement Width, Terrain (Rise +Fall),
Curvature Year-Wise Roughness, Traffic
with category and Traffic Growth Factor
Calculate Year-wise VOC for Vehicle of Different Categories
Calculate traffic for each category using traffic growth
Calculate Year-wise VOC for All Vehicles in Each Category by Multiplying Number of Vehicles in that Category
Calculate Year-wise Net VOC by adding VOC of all categories of vehicles
Report
Year wise VOC

Fig. 13.1. Flow Chart for Vehicle Operating Cost

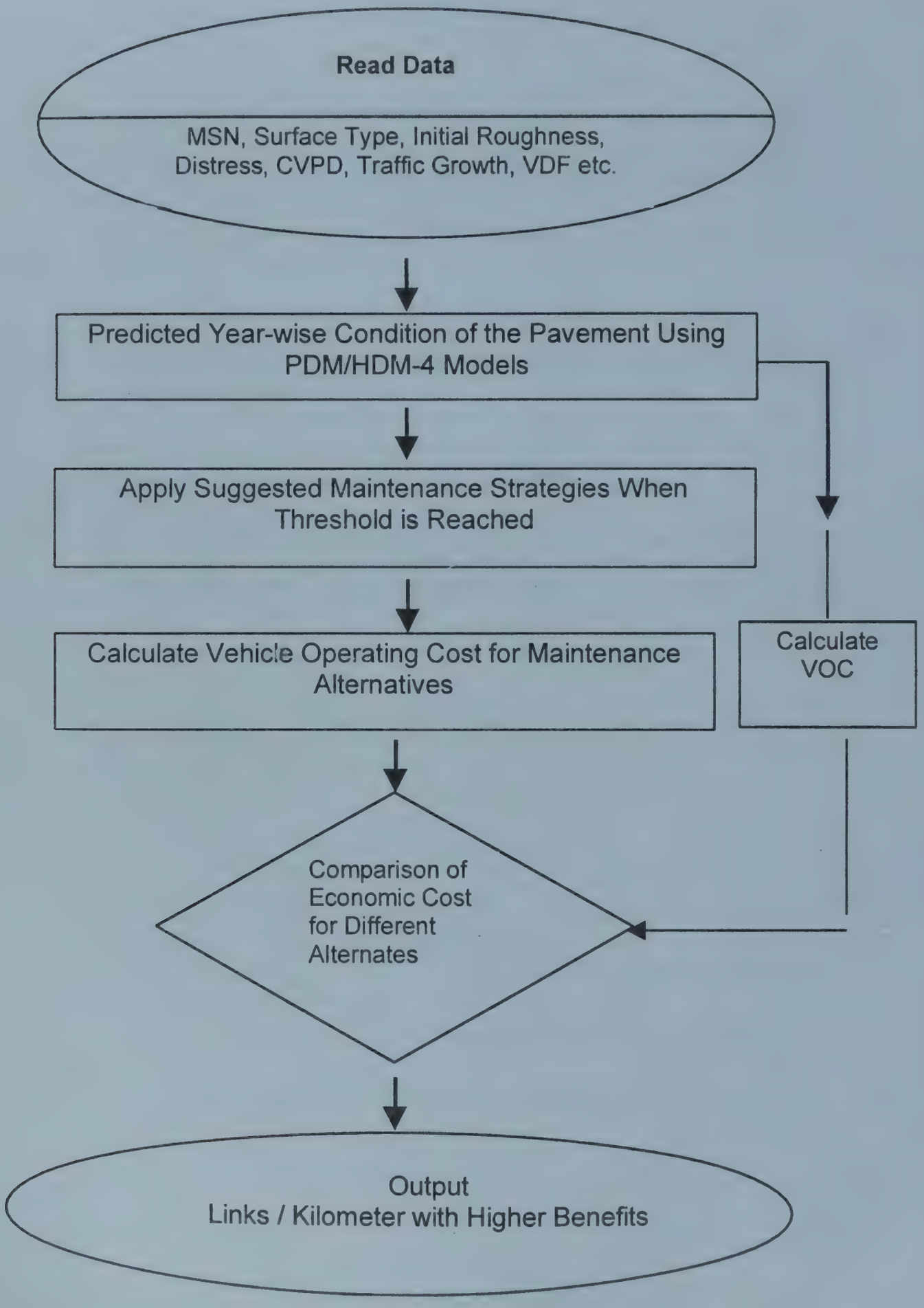

Read Data
MSN, Surface Type, Initial Roughness, Distress, CVPD, Traffic Growth, VDF etc.
Predicted Year-wise Condition of the Pavement Using PDM/HDM-4 Models
Apply Suggested Maintenance Strategies When Threshold is Reached
Calculate Vehicle Operating Cost for Maintenance Alternatives
Calculate VOC
Comparison of Economic Cost for Different Alternates
Output
Links / Kilometer with Higher Benefits

Fig. 13.2. Flow Chart for Prioritisation

13.6.1. Net present value (NPV): In this method all the values of costs and benefits are reduced at the present cost by using a discount rate fixed by the agency or at which the money is borrowed from the market. Comparison is made between the sum of the present worth of benefits and costs for maintenance and vehicle operation during each year of analysis period. The net present value is defined by the following formula:

$$NPV = -Co + ((b_1-c_1)/(1+i)\ ) + ((b_2-c_2)/(1+i)^2)+ \ldots.+ ((b_n-c_n)/(1+i)^n)$$

Where,

NPV	=	Net present value
Co	=	Investment cost
B	=	Present value of benefit flow b_1, b_2, ...,b_n
C	=	Present value of cost flow c_1, c_2,.....,c_n
t	=	1....n time (years)
i	=	discount rate (per cent)

This criteria states that investments benefit the economy when the difference between discounted benefit and cost is positive. Therefore, maintenance with positive and maximum NPV is given the priority.

13.6.2. Internal Rate of Return (IRR): The internal rate of return of an investment is the rate of interest or return which would make the discounted present value of the expected future marginal returns of investment exactly equal to the current cost of investment. In other words, it is the rate of return at which the net present value of the alternative is zero. Maintenance with high IRR will qualify for prioritisation. As per Govt. norms IRR should not be less then 12 per cent per year. Following formula is used to calculate the IRR :

$$\sum_{t=0}^{n} B_{x,t} / (1+r)^t = \sum_{t=0}^{n} C_{x,t} / (1+r)^t$$

Where,

$B_{x,t}$	=	Benefits net of operating costs during year t for x maintenance
$C_{x,t}$	=	Capital outlay during year t
r	=	Internal rate of return
t	=	Time in years

13.6.3. Benefit - cost analysis: The benefit - cost analysis involves the determination of the ratio of estimated benefits to the estimated cost and the ratio is used to determine whether or not the proposed expenditure should be recommended. This is defined as:

BCR = (Difference in road user costs)/(Difference in improvement costs)

$$BCR = (R^1 - R^2)/(H^2 - H^1)$$

Where,

R^1 = Total annual VOC for maintenance alternate^1
R^2 = Total annual VOC for maintenance for alternate^2
H^1 = Maintenance cost for alt^1
H^2 = Maintenance cost for alt^2

On this basis relative values of other alternatives can be calculated. The maintenance with maximum ratio (but all greater than 1) will get top priority.

Generally, net present value method is used for economic analysis of road projects.

14. PROCEDURE FOR PRIORITISATION OF STRATEGIES

To facilitate better understanding of the above guidelines presented in the previous sections, numerical examples have been worked out to demonstrate what all is involved in the decision making process. The examples given in **Annexure-1** illustrate the different maintenance strategies which include study of effect of two different specifications and delayed maintenance. The procedure involved is given in the following steps.

Step 1 : Collect the information for following parameters for road links/length for which maintenance prioritisation/optimisation is to be carried out

- Pavement width
- Subgrade CBR
- Pavement layer composition with type and thickness
- Terrain
- Traffic volume with category
- Traffic growth factor
- Vehicle damage factor
- Maintenance alternatives with their costs

Step 2 : Calculate modified structural number, calculate year-wise traffic for different categories of vehicles by assuming suitable growth factor.

Step 3 : Using the data collected, as at step 1, run "PDM" or any other software package to obtain deterioration trend and roughness progression.

Step 4 : Calculate year-wise vehicle operating cost from vehicle operating cost equations.

Step 5 : Decide maintenance strategy depending upon the road category yet roughness level say 4000 mm/km.

Step 6 : Apply maintenance strategy as decided.

Step 7 : Calculate Modified Structural Number (MSN) for changed thickness due to maintenance carried out.

Step 8 : Adopt the initial roughness value as the case may be, as mentioned in Section 13.5.2.6. Run PDM again with the new roughness (after maintenance) to obtain roughness progression.

Step 9 : Calculate vehicle operating cost for the roughness progression.

Step 10 : Compare vehicle operating cost without renewal *vis-à-vis* vehicle operating cost with renewal cost.

Step 11 : Calculate saving in vehicle operating cost and net benefit.

Step 12 : Calculate Net Present Value (NPV) using market lending interest rate.

Step 13 : Similar steps can be repeated for other maintenance strategies.

Step 14 : Strategy with higher NPV will get the priority.

14.1. Inference Drawn from the Solved Examples

The examples given in the ***Annexure-1*** are solved following the steps explained earlier. The summary output of these examples is tabulated below :

Existing Pavement Composition : 40 mm BC + 50 mm DBM + 225 mm WBM + 400 mm GSB

Alternate 1 : Overlaying by 25 mm SDBC
Alternate 2 : Overlaying by 25 mm BC

Benefits of Different Maintenance Strategies in Comparison to do Nothing Techniques	
Strategy	Benefit Derived from NPV @ 12 per cent Rate of Interest Rs. lakhs/km
Alternate 1 (25 mm SDBC)	37.85
Alternate 2 (25 mm BC)	43.17

As seen from the above tabulated figures, the highest NPV is derived from alternate 2 and hence is the best strategy. By adopting the best alternative strategy through such an exercise will result in economic savings. The strategy of deferred maintenance will result in a net loss of Rs. 1.6 lakhs for deferring the maintenance by a year (Example-III).

15. CONCLUDING REMARKS

The maintenance of road pavements has never been viewed as a serious issue, till recently, by the concerned and has always been sidelined. The ill effects and loss to economy by poorly maintained roads are quite pronounced. The construction of new roads has always got preference over the maintenance of existing roads. It is high time that the maintenance aspects, such as, objective assessment of actual requirements, use of new techniques, proper fund allocations and effective implementation are well addressed. Though, guidelines are available on condition based maintenance, selection of appropriate technologies, quality control, strengthening of weak pavements, etc., these are not being followed in good spirit. Hence, there is a need for a systematic approach in implementing a planned and an adequate maintenance strategy.

The guidelines presented here, through the preceding sections, have been framed keeping in view the existing maintenance practices, norms, their shortfalls and needed changes. A scientific aptitude is the only way to rationally utilize the scarce resources to optimise the benefits. Pavement Maintenance Management System (PMMS), when developed and adopted to the requirements of our roads of different categories, are expected to yield fruitful results. The guidelines are aimed to give proper directives for developing appropriate MMS for taking care of maintenance activities through the following recommendations:

1. The current maintenance practices/norms for primary, secondary and urban roads really do not support technically and financially the criteria for providing satisfactory level-of-service and keep the roads in traffic worthy condition. The service conditions expressed through a 'serviceability index' shall form the basis of maintenance and fixing maintenance quality levels. Meeting the needs of road users and their safety shall be an important aspect in deciding and implementing any maintenance activity. The maintenance norms and allocations shall be viewed as 'need based' and be rationally structured to take care of our roads.

2. Developing and adopting a practical and workable 'Maintenance Management System' can give a scientific solution to the maintenance and allocation problems. The work already done on various MMS has been reviewed and the main features of each system indicated.

3. Development of any Maintenance Management System is facilitated only by a proper database. Hence, the elements of database shall be well identified before proceeding to actual data collection. The database shall be well organised, accessible and flexible for upgradation.

4. There are tremendous advancements in data collection methods and techniques. A vide variety of equipments are globally available, as mentioned in Chapter 6. For an objective data collection, certain equipments are essential. In order to make inputs

into database for MMS, the minimum equipment requirements are recommended. The data collection shall be invariably done and ascertained qualitatively and quantitatively to decide the maintenance measures.

5. The data collection shall be undertaken with equipments or otherwise, as the case may be, in a systematic manner with methodology as suggested in the guidelines. The calibration of equipments wherever required and as specified, must be undertaken. If the situation demands, additional calibration operations shall be carried out to ensure quality of data collected. A well planned data collection will make meaningful inputs into any MMS.

6. The guidelines suggest the methodology for equipment operation, calibration and periodicity of updating and the minimum requirement of manpower which shall be followed and adhered to. If required, these minimum requirements shall be enhanced to produce more speedy data collection under specific conditions.

7. The various activities involved in database development have been discussed. These shall be followed systematically to ensure error free inputs. The hardware and software features and the minimum requirement for MMS operations have also been indicated as a rough guide.

8. The methodology for analysis of basic data for inputs has been provided. The use of appropriate analysis tools shall be carefully decided. The 'Pavement Deterioration Models' and the PDM package are the only Indian tools available for local condition that must be used, but have some limitations having been developed for certain conditions only. Another set of tools available is HDM-4 which can be used after proper calibration.

9. Organisational requirements and institutional arrangements required for development and implementation of MMS have been presented. The limitations of existing setup and needed modifications have been highlighted and shall be considered for restructuring of the existing system. The importance of training shall be duly taken care of.

10. The intervention levels for primary, secondary and urban roads have been suggested. In the development of any MMS all these condition parameters are not taken as direct components, but the resulted roughness shall only be taken into account for the purpose.

11. The different techniques for economic analysis have been described. For selection of any maintenance strategy, Net Present Value (NPV) based technique is suggested.

12. Maintenance strategies shall be best judged based on various alternatives/treatments available. The alternatives in the guidelines are just indicative. The roughness levels given for improved conditions are based on limited data available and hence any other values if appropriate, may also be considered. The different available methods for economic analysis are discussed for choosing the most appropriate one amongst them.

13. The information contained in this report is based on published literature and also from relevant studies conducted in India and in abroad.

REFERENCES

1. Bennet, Christopher R., "Implementing a National Pavement Management System: New Zealand's Pragmatic Approach", Proceedings, 1st European Pavement Management Systems Conference, Budapest, Hungary, 2000.
2. Bennet, David, "Pavement Management System Developments in Australia", Proceedings of International Conference on Pavement and Bridge Management, Beijing, China, pp 8-16, 1998.
3. Bham, G.H., Gharaibeh, N.G. and Laura, Heckel, "Illinois's Experience with Pavement Analysis and Management Systems", 80th Annual Meeting, Transportation Research Board, Washington D.C., 2001.
4. Chakrabarti, S., Rawat, M.S. and Mondal, B., "Highway Design and Maintenance Standards Model (HDM) : Calibration and Adaptation to Indian Conditions" IRC Journal, Vol. 56(1), pp 75-101, 1995.
5. Deck, Choo Sang and Paul Autret, "Setting up a Road Maintenance Management System in Korea", Proceedings of 11th IRF World Meeting, Seoul, Korea. Vol. IV, pp 26-31, 1989.
6. Fujii, Haruho and Makoto Mizoguchi, "A Rational Maintenance Plan of Pavement", Proceedings of 11th IRF World Meeting, Seoul, Korea. Vol. IV, pp 7-9, 1989.
7. Gillahm, David and Batra, D.S., "Highway Maintenance-The U.K. Approach and its Relevance to India", Proceedings, National Seminar on Highway Maintenance and Rehabilitation, IRC, pp 1-17, 1999.
8. Gryteselv, Dagfin; Haugodegard, Thorleif and Even K. Sund, "PMS99 – The New Norwegian Pavement Management System", Proceedings, 1st European Pavement Management Systems Conference, Budapest, Hungary, 2000.
9. Haas, R.C.G. and Hudson, W.R., "Pavement Management System", McGraw-Hill Book Company, New York, 1978.
10. Haas, Ralph and Tom Kazmierowski, "Implementation Experience of a New Pavement Design and Management Guide", 4th International Conference on Managing Pavements, Durban, South Africa, 1998.
11. Hans, Z.N., Smadi, O.G. and T.H. Maze, "Iowa's Pavement Management Program Database : Issues and Design Considerations", IPMP Project, Iowa State Department of Transportation, USA, 1996.
12. Heleven, L.J.E., "First Experience with PMS in Flanders (Belgium)", Proceedings, 1st European Pavement Management Systems Conference, Budapest, Hungary, 2000.
13. Henderson, M.G., Gryp, A. and Rhode, G. "Pavement Management Practice in the Province of the Western Cape", Proceedings, 4th International Conference on Managing Pavements, Durban, South Africa, 1998.

14. Hodges, J.W., Rolt J. and Jones T.E., "The Kenya Road Transport Cost study : Research on Road Deterioration", TRRL Laboratory Report, 673.

15. Howard, K.R., Robertson, N.F. and R. Fransisco, "Introduction of Investment Analysis into Pavement Management Practices in Philippines", Proceedings, 3rd International Conference on Managing Pavements, San Antonio, Texas, USA, 1994.

16. Hurst, Bernard B. "ODOT's Pavement Management System", Proceedings of 11th IRF World Meeting, Seoul, Korea. Vol. IV, pp 22-25, 1989.

17. Indian Roads Congress, "Manual on Economic Evaluation of Highway Projects in India", IRC:SP 30, New Delhi, 1993.

18. Indian Roads Congress, "Code of Practice for Maintenance of Bituminous Surfaces of Highways", IRC:82-1982, New Delhi, 1982.

19. Jain S.S. and A.K. Gupta, "Development of Pavement Management System for Indian Highway Network", a R&D Project Proposal Submitted to AICTE, New Delhi by COTE, Department of Civil Engineering, UOR, Roorkee, 1994.

20. Jain, S.S., Gupta, A.K., and Khanna, S.K., "Development of Maintenance and Rehabilitation Investment Strategy for Flexible Pavements", IRC Journal, Vol. 57, No. 2, pp. 367-418, 1996.

21. Jain, S.S., Parida, M. and Rawat, M.M.S., "A Rational Approach for Pavement Management System for Urban Roads" Highway Research Bulletin, IRC, No.61, pp. 69-99, 1999.

22. Kulkarni, R., and Finn, F.N., "Development of a Pavement Management System", Transportation Research Record 602, pp. 117-121, 1976.

23. Lang, Johan and Jaro Potucek, "Pavement Management Systems in Sweden", Proceedings, 1st European Pavement Management Systems Conference, Budapest, Hungary, 2000.

24. Lepert, Ph. and Joubert, P., "Recent Developments in the Pavement Management Systems in France", Proceedings, 4th International Conference on Managing Pavements, Durban, South Africa, 1998.

25. Li, Ningyuan and Hass, R.C.G., "Special Implementation of Pavement Management for a Large Highway Network in a Developing Area of China", Proceedings, 3rd International Conference on Managing Pavements, San Antonio, Texas, USA, 1994.

26. Majidzadeh, Kamran, Vedaie, Bezhad and Kennedy, James C., "Pavement Management System to Maximise Pavement Investment and Minimize Costs", Transportation Research Record No. 1272, TRB, pp. 65-79, 1990.

27. Ministry of Shipping & Transport (Roads Wing), "Manual for Maintenance of Roads", IRC, New Delhi, 1989.

28. Ministry of Road Transport & Highways, "Report of the Committee on Norms for Maintenance of Roads in India", Indian Roads Congress, New Delhi, 2001.

29. Molzer, C., Litzka, J., Breyer, G. and Feisenstein, K., "Implementation of PMS for the Austrian Federal Road Network", Proceedings, 4th International Conference on Managing Pavements", Durban, South Africa, 1998.

30. "Pavement Performance Study – Study on Existing Pavement Sections", Vol.II, Central Road Research Institute, Sept. 94.

31. "Pavement Performance Study – Study on New Pavement Sections", Phase-I, Central Road Research Institute, May 2000.

32. Peroni, Giorgipo, and Battiato, Gianfranco, "Pavement Management Systems for Italian Primary and Secondary Roads", Conference Proceedings: ICORT – 95, University of Roorkee, 1995.

33. Pilson, C.C. and W.R. Hudson, "The Feasibility of Integrating Network and Project Level Pavement Management in Texas", Proceedings, 4th International Conference on Managing Pavements, Durban, South Africa, 1998.

34. Ramesh, C.R. and Veeraragavan, A., "Life Cycle Cost Analysis of Pavements for Planning Maintenance Budget," IRC Journal, vol. 60(2), pp. 323-353, 1999.

35. Reddy, B.B., Nagaraju, K. and Veeraragavan, A., "Practical Applications of Flexible Pavement Deterioration Models" Highway Research Bulletin, IRC, No. 61, pp. 21-67, 1999.

36. Reddy, B. B. and Veeraragavan, A., "Methodology for Sample Size Determination in Pavement Performance Data Collection", Indian Highways, IRC, Vol. 26(11), pp. 15-27, 1998.

37. Saxena, Rajendra Kumar, "Road Management in West Germany", Indian Highways, IRC, October, 1993, pp. 31-38, 1993.

38. Sharma, S.C. and Pandey, R.K., "Road Development and Maintenance Investment Decision Model Based on Indian Research", IRC Journal Vol. 58-3, pp. 386-425, 1997.

39. Sikka, R.P., "Paper for Panel Discussion on Pavement Management System", IRC Journal, Vol. 51, No. 3, pp. 691-705, 1990.

40. Solminihac, Hernan Eduardo, "Pavement Maintenance Management Research : The Chilean Experience on Asphalt Pavements", Proceedings of 11th IRF World Meeting, Seoul, Korea, Vol. IV, pp. 13-17, 1989.

41. Sood, V.K. and Sharma, B.M., "An Input towards Development of Pavement Management System In India" Proceedings, 7th Conference of the Road Engineering Association of Asia and Australia, June 1992, Singapore. pp. 811-819, 1992.

42. Sood, V.K. and Sharma, B.M., "Development of Pavement Deterioration Models for Indian Conditions", IRC Journal, Vol. 57(3), pp. 481-528, 1996.

43. Sood, V.K., "Data Requirements for Maintenance Planning and Equipment Needed for Collection", Proceedings, IRC Seminar on Perspective Planning for Road Development in India, New Delhi, pp. II-133 to 139, 1996.

44. Sood, V. K. and Sitaramanjaneyulu, K., "Area Review Paper on Pavement Performance Evaluation", IRC 59th Annual Session, Hyderabad, pp. 1-35, 1999.

45. Ulliditz, Peter, "A PMS Based on the Analytical-Empirical Method", Pavement Analysis, Chapter 11, pp. 286-313, 1987.

46. Vervenne, P.J., Janssens, R., Gorski, M.B., Lemlin, M. and Ghilain, E., "Pavement Management System for Belgian State Highway and Low Volume Roads", Proceedings, ICORT-88, University of Roorkee, Roorkee, 1988.

47. William, D.O. Paterson, "Road Deterioration and Maintenance Effects," Model for Planning and Management, A World Bank Publication, 1987.

48. Zimmerman, Kathryn A. and Frank Bothello, "Pavement Management Trends in the United States", Proceedings, 1st European Pavement Management Systems Conference, Budapest, Hungary, 2000.

PROFORMAE

Proforma 7.1

PACKAGE/PROJECT DETAILS

GENERAL INVENTORY

Name of the Road :
Category of the Road :
Chainage of Test Section Km……..to Km…….
Chainage of Sub-Section : Km……..to Km…….
Test Section No. (If applicable)

Type of Surface :
Carriageway Width (m) :
Date of Observation :
Weather Condition :
Area of the Section :

Chainage	Crust Type	General Geometry (Straight/Curve, etc.)	Shoulder Type and Width	Junction	CD	Bridge	Water Table	Height of Embankment	Depth of Cutting	Other Features	Remarks

Recorded by :

PACKAGE / PROJECT DETAILS

ROAD GEOMETRICS - GRADIENT

Name of the Road :
Category of the Road :
Chainage of Test Section Km.....to Km.....
Chainage of Sub-Section : Km.....to Km.....
Test Section No. (If applicable)

Type of Surface :
Carriageway Width (m) :
Date of Observation :
Weather Condition :
Area of the Section :

Link No.	Kilometer Stone	Type of Vertical Curve	Distance Counter Reading		Gradometer Readings	
			Starting	End	Plus Cumulative	Minus Cumulative

Recorded by :

Proforma 7.3

PACKAGE / PROJECT DETAILS

ROAD GEOMETRICS - CURVATURE

Name of the Road :
Category of the Road :
Chainage of Test Section Km.....to Km.....
Chainage of Sub-Section : Km.....to Km.....
Test Section No. (If applicable)

Type of Surface :
Carriageway Width (m) :
Date of Observation :
Weather Condition :
Area of the Section :

Link No.	Kilometer Stone	Type of Horizontal Curve	Distance Counter Reading		Gyrocompass Readings	
			Starting	End	Start of Curve	End of Curve

Recorded by :

PACKAGE/PROJECT DETAILS

PAVEMENT SURFACE CONDITION MEASUREMENT IN THE FIELD

Name of the Road :
Category of the Road :
Chainage of Test Section — Km.....to Km.....
Chainage of Sub-Section : — Km.....to Km.....

Type of Surface :
Carriageway Width (m) :
Date of Observation :
Weather Condition :
Area of the Section :

Test Section No. (If applicable)

Left/Right/ Central Strip/Segment	Cracks Type Size Area (m) (m^2)	Patch Work Size Area (m) (m^2)	Potholes Size Area (m) (m^2)	Bleeding Size Area (m) (m^2)	Depression/ Settlement Size Area (m) (m^2)	Edge Breaking Size Area (m) (m^2)	Ravelling Size Area (m) (m^2)	Shoving Size Area (m) (m^2)	Remarks (Drainage and Shoulder Condition)
Total									

Note : Note down the depth of potholes (in cm) also size of pothole

Recorded by :

Proforma 7.5

PACKAGE/PROJECT DETAILS

DATA SHEET FOR ROUGHNESS MEASUREMENTS BY ROUGHOMETER

Name of the Road:
Category of the Road:

Type of Wearing Course :
Surface Condition (Visual) :
Date of Observation :

Chainage of Test Section : Km.....to Km.....
Test Section No. (If applicable)

Sl. No.	Wheel Path	Trial No.	Number of Distance/ Wheel Revolutions Counts	Bump Integrating Counter Reading (mm)	Roughness Value (mm/km)	Average Roughness Value for each wheel path (mm/km)	Average Roughness Value for the section (mm/km)

Recorded by :

PACKAGE/PROJECT DETAILS

DATA SHEET FOR CALIBRATION OF FIFTH WHEEL BUMP INTEGRATOR/VMBI

Name of the Road :
Category of the Road :

Type of Wearing Course :
Surface Condition (Visual) :
Date of Observation :
IRI (International Roughness Index) m/km.

Chainage of Test Section : Km..... to Km.....
Test Section No. (If applicable)

Test Section No.	Location of wheel path left/center/ right	BI counter reading for 100 m					No. of wheel revolutions for 100 m					U.I. values mm/km					Av. U.I. value mm/km.
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	

Note : In case, the calibration is done with standard BI, the data from standard BI is also recorded in this same Proforma.

Recorded by :

Proforma 7.7

PACKAGE / PROJECT DETAILS

DATA ON DEFLECTION MEASUREMENT

Name of the Road :
Category the Road :
Test section No. (If applicable:
Chainage of Test Section: Km.....to Km.....

Weather Condition :
Shade Temperature :
Pavement Temperature :

Moisture Content :
Surface Condition (Visual) :
Date of Observation :

Dial Gauge Reading Particulars	Test Point No.																					Remarks
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
Initial																						
1																						
2																						
3																						
Ave																						
Intermediate																						
1																						
2																						
3																						
Ave																						
Final																						
1																						
2																						
3																						
Ave																						
Rebound deflection (mm)																						
Corrected rebound deflection after temperature correction (mm)																						
Corrected rebound deflection after seasonal correction factor (mm)																						
Corrected rebound deflection (mm)																						
Mean corrected rebound deflection (mm)																						
Standard deviation (mm)																						
Characteristic rebound deflection (mm)																						
Condition of test point																						

Recorded by:

PACKAGE/PROJECT DETAILS

DATA ON MOISTURE CONTENT DETERMINATION

Name of the Road :
Category of the Road :
Chainage of Test Section : Km.....to Km.....

Date of Observation :
Weather Condition :
Location of test point :

Test Section No. (If applicable)

Tin No.	Wt. of tin (gms)	Wt. of tin+ Wet Soil (gms)	Wt. of tin + Dry Soil (gms)	Wt. of Dry Soil (gms)	Wt. of Water (gms)	Moisture content (%)	Average Moisture content (%)	Depth of water table in the adjoining fields	Remarks

Note : Minimum two tests are carried out for moisture content determination from the same pit

Recorded by :

Proforma 7.9

PACKAGE/PROJECT DETAILS

TEST PIT OBSERVATIONS - CRUST DETAILS

Name of the Road :
Category of the Road :
Chainage of Test Section — Km.....to Km.....
Chainage of Sub-Section : — Km.....to Km.....
Test Section No. (If applicable)

Type of Surface :
Carriageway Width (m) :
Date of Observation :
Weather Condition :
Area of the Section :

Chainage (Km)	Surface		Base		Subbase		Total Thick- (mm)	Subgrade			Shoulder		Year of	
	Type	Thick-ness (mm)	Type	Thick-ness (mm)	Type	Thick-ness (mm)		Type of Soil	Field Density (gm/cc)	CBR (%)	Surface Type	Composition and Thick-ness of Layers (mm)	Last Renewal	Widening

Recorded by :

PACKAGE/PROJECT DETAILS

AXLE LOAD SURVEYS

Name of the Road:
Location of Survey Point : Km.....

Name of Supervisor :
Date :
Weather :
Time (Hours) : From..... to.....

Test Section No. (If applicable)
Chainage of Test Section : From..... to .....
Direction of Traffic : From ..... to.....

Sr. No.	Vehicle Registration No.	Type of Vehicle (Bus/Truck, etc.)	Axle Configuration Code	Type of Commodity Carried	Unladen Weight (Tonnes)	Registered G.L.W. (Tonnes)	Wheel Weight (Tonnes)			
							Front	Rear 1	Rear 2	Rear 3

Recorded by :

Proforma 7.11

PACKAGE/PROJECT DETAILS

TRAFFIC VOLUME SURVEYS

Name of the Road:

Name of Supervisor :
Date :
Weather :
Time (Hours) : From..... to.....

Test Section No. (If applicable)
Chainage of Test Section : Km..... To Km.....
Location of Traffic Count Point :
Direction of Traffic : From ..... to.....

Pedal Cycles	Cycle Rick-shaws	Hand/ Animal Drawm Carts	Scooters /Motor Cycles	Three Wheelers (Auto-Rick-shaw)	Cars/ Jeeps	Pick-up Vans & Tempos	Light Commer-cial Vehicles	Light Passen-ger Vehicles	Heavy Commercial Vehicles 2-Axle Multi-axles (Sp. Code)	Buses	Tractor, Tractor Trolley	Others (Specify)

Recorded by :

Annexure-1

EXAMPLE-I

Terrain	Plain
Rise+Fall	5 m/km
Two-lane Road	7 m
CBR	8%
Pavement Composition	40 BC+50 DBM+225 WBM+400 Gravel
MSN	5.02
VDF	4.00
CVPD	4000
Traffic Growth	7.50%
Renewal Type	25 mm SDBC
Initial Roughness after Renew	2000 mm/km
Renewal cost	Rs. 4.50 lakh/7./km
MSN after Renewal	5.27

Year	Car/Day 400	LCV/Day 200	Bus/Day 150	Truck/Day 3500	M-axle/Day 150
	Car/Year	LCV/Year	Bus/Year	Truck/Year	M-axle/Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	235913	397143	259636	6673237	490604	4619	80.57
2010	281534	440018	291072	7464160	549530	5685	90.26
2011	337296	488075	326828	8361267	616483	6791	101.30
2012	404856	541672	367252	9372823	692101	7916	113.79
2013	484759	600730	412268	10496984	776245	9016	127.71
2014	580034	666094	462676	11752912	870384	10109	143.32
2015	750489	755457	535819	13555924	1006433	12000	166.04

Year	Car/ Year	LCV/ Year	Bus/ Year	Trucks/ Year	M-axle/ Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	182509	368743	234199	6053276	443478	2000	72.82
2010	199767	398470	253595	6552002	480133	2184	78.84
2011	219323	430972	274931	7100007	520440	2399	85.46
2012	242450	467051	298886	7713924	565656	2684	92.88
2013	272038	508334	326878	8428486	618413	3121	101.54
2014	319719	560731	364212	9372849	688536	4031	113.06
2015	388526	624532	411294	10556191	776756	5282	127.57

Year	Cost of Renewal Rs. (Lakhs)	VOC W.O. Renew Rs. (Lakhs)	VOC W. Renew Rs. (Lakhs)	VOC Saving Rs. (Lakhs)	Net Benefit Rs. (Lakhs)
2002	0.00	43.56	43.56	0.00	0.00
2003	0.00	47.00	47.00	0.00	0.00
2004	0.00	50.73	50.73	0.00	0.00
2005	0.00	54.77	54.77	0.00	0.00
2006	0.00	59.34	59.34	0.00	0.00
2007	0.00	64.88	64.88	0.00	0.00
2008	4.50	72.13	72.13	0.00	-4.50
2009	0.00	80.57	72.82	7.74	7.74
2010	0.00	90.26	78.84	11.42	11.42
2011	0.00	101.30	85.46	15.84	15.84
2012	0.00	113.79	92.88	20.91	20.91
2013	0.00	127.71	101.54	26.17	26.17
2014	0.00	143.32	113.06	30.26	30.26
2015	0.00	166.04	127.57	38.47	38.47
			NPV @ 12 per cent	Rs. (Lakhs)	37.85

EXAMPLE-II

Terrain	Plain
Rise+Fall	5 m/km
Two-lane Road	7 m
CBR	8 per cent
Pavement Composition	40 BC+50 DBM+225 WBM+400 Gravel
MSN	5.02
VDF	4.00
CVPD	4000
Traffic Growth	7.50 per cent
Renewal Type	25 mm BC
Initial Roughness after Renew	1800 mm/km
Renewal Cost	Rs. 5.25 lakh/7m/km
MSN after Renewal	5.32

Year	Car/Day 400	LCV/Day 200	Bus/Day 150	Truck/Day 3500	M-axle/Day 150
	Car/Year	LCV/Year	Bus/Year	Truck/Year	M-axle/Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	235913	397143	259636	6673237	490604	4619	80.57
2010	281534	440018	291072	7464160	549530	5685	90.26
2011	337296	488075	326828	8361267	616483	6791	101.30
2012	404856	541672	367252	9372823	692101	7916	113.79
2013	484759	600730	412268	10496984	776245	9016	127.71
2014	579750	665999	462585	11750725	870216	10104	143.29
2015	750489	755457	535819	13555924	1006438	12000	166.04

Year	Car/ Year	LCV/ Year	Bus/ Year	Trucks/ Year	M-axle/ Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	178967	366659	232362	6008371	440071	1800	72.26
2010	194132	395187	250696	6481160	474758	1892	77.96
2011	210706	426008	270540	6992714	512297	1990	84.12
2012	228851	459322	292035	7546610	552953	2095	90.80
2013	250050	496099	315996	8162899	598242	2261	98.23
2014	277068	537996	343854	8876649	650819	2570	106.86
2015	323215	592173	381981	9843335	722495	3404	118.63

Year	Cost of Renewal Rs. (Lakhs)	VOC W.O. Renew Rs. (Lakhs)	VOC W. Renew Rs. (Lakhs)	VOC Saving Rs. (Lakhs)	Net Benefit Rs. (Lakhs)
2002	0.00	43.56	43.56	0.00	0.00
2003	0.00	47.00	47.00	0.00	0.00
2004	0.00	50.73	50.73	0.00	0.00
2005	0.00	54.77	54.77	0.00	0.00
2006	0.00	59.34	59.34	0.00	0.00
2007	0.00	64.88	64.88	0.00	0.00
2008	5.25	72.13	72.13	0.00	-5.25
2009	0.00	80.57	72.26	8.30	8.30
2010	0.00	90.26	77.96	12.30	12.30
2011	0.00	101.30	84.12	17.18	17.18
2012	0.00	113.79	90.80	22.99	22.99
2013	0.00	127.71	98.23	29.48	29.48
2014	0.00	143.29	106.86	36.43	36.43
2015	0.00	166.04	118.63	47.41	47.41
			NPV @ 12 per cent	Rs. (Lakhs)	43.17

EXAMPLE-III

Terrain	Plain
Rise+Fall	5 m/km
Two-lane Road	7 m
CBR	8 per cent
Pavement Composition	40 BC+50 DBM+225 WBM+400 Gravel
MSN	5.02
VDF	4.00
CVPD	4000
Traffic Growth	7.50 per cent
Renewal Type	25 mm BC
Initial Roughness after Renew	1800 mm/km
Renewal Cost	Rs. 5.25 lakh/7./km
MSN after Renewal	5.32

Year	Car/Day 400	LCV/Day 200	Bus/Day 150	Truck/Day 3500	M-axle/Day 150
	Car/Year	LCV/Year	Bus/Year	Truck/Year	M-axle/Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055
2016	401857	200928	150696	3516247	150559
2017	431996	215998	161999	3779966	161851
2018	464396	232198	174148	4063463	173989

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	235913	397143	259636	6673237	490604	4619	80.57
2010	192389	394159	249790	6458999	473076	1800	77.68
2011	208692	424826	269498	6967247	510365	1892	83.81
2012	226509	457958	290830	7517167	550719	1990	90.43
2013	246015	493772	313938	8112606	594425	2095	97.61
2014	268804	533307	339696	8775116	643110	2261	105.60
2015	297849	578345	369643	9542397	699630	2570	114.88
2016	347456	636586	410630	10581585	776682	3404	127.53
2017	410321	703177	458412	11788677	866386	4363	142.27

Year	Car/ Year	LCV/ Year	Bus/ Year	Trucks/ Year	M-axle/ Year
2002	146000	73000	54750	1277500	54700
2003	156950	78475	58856	1373313	58803
2004	168721	84361	63270	1476311	63213
2005	181375	90688	68016	1587034	67954
2006	194978	97489	73117	1706062	73050
2007	209602	104801	78601	1834016	78529
2008	225322	112661	84496	1971568	84419
2009	242221	121111	90833	2119435	90750
2010	260388	130194	97645	2278393	97556
2011	279917	139958	104969	2449272	104873
2012	300911	150455	112841	2632968	112738
2013	323479	161739	121305	2830440	121194
2014	347740	173870	130402	3042723	130283
2015	373820	186910	140183	3270928	140055
2016	401857	200928	150696	3516247	150559
2017	431996	215998	161999	3779966	161851

ECONOMIC VEHICLE OPERATING COST (USING EQUATIONS)

Year	Car	LCV	Bus	Trucks	M-axle	Roughness mm/km	T.Voc Rs. (lakhs)
2002	107873	221006	140058	3621575	265255	1800	43.56
2003	117083	238242	151144	3907424	286229	1898	47.00
2004	127153	256865	163146	4216776	308932	2002	50.73
2005	138212	277016	176164	4552145	333552	2115	54.77
2006	151534	299492	190881	4930312	361359	2316	59.34
2007	170110	326011	208799	5388024	395138	2758	64.88
2008	199163	359217	232290	5983027	439282	3629	72.13
2009	178967	366659	232362	6008371	440071	1800	72.26
2010	194132	395187	250696	6481160	474758	1892	77.96
2011	210706	426008	270540	6992714	512297	1990	84.12
2012	228851	459322	292035	7546610	552953	2095	90.80
2013	250050	496099	315996	8162899	598242	2261	98.23
2014	277068	537996	343854	8876649	650819	2570	106.86
2015	323215	592173	381981	9843335	722495	3404	118.63
2016	381694	654118	426430	10966211	805941	4363	132.34
2017	454347	724203	477571	12254076	901837	5403	148.12

Year	Cost of Renewal Rs. (Lakhs)	Cost of Renewal Rs. (Lakhs)	VOC W.O. Renew Rs. (Lakhs)	VOC W. Renew Rs. (Lakhs)	VOC Saving Rs. (Lakhs)	Net Benefit Rs. (Lakhs)
2002	0.00	0.00	43.56	43.56	0.00	0.00
2003	0.00	0.00	47.00	47.00	0.00	0.00
2004	0.00	0.00	50.73	50.73	0.00	0.00
2005	0.00	0.00	54.77	54.77	0.00	0.00
2006	0.00	0.00	59.34	59.34	0.00	0.00
2007	0.00	0.00	64.88	64.88	0.00	0.00
2008	0.00	0.00	72.13	72.13	0.00	0.00
2009	0.00	5.25	80.57	72.26	8.30	3.05
2010	5.25	0.00	77.68	77.96	-0.28	4.97
2011	0.00	0.00	83.81	84.12	-0.32	-0.32
2012	0.00	0.00	90.43	90.80	-0.37	-0.37
2013	0.00	0.00	97.61	98.23	-0.63	-0.63
2014	0.00	0.00	105.60	106.86	-1.26	-1.26
2015	0.00	0.00	114.88	118.63	-3.75	-3.75
			NPV @ 12 per cent		Rs. (Lakhs)	1.60